Environmental impacts from Danish fish products

hot spots and environmental policies

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App. 1: Description of Fishing Gear

In Denmark there have been a long tradition of applying different fishing gears and the vessel can often be rigged with different fishing gears depending on the season and the availability of fish stocks. This appendix explains some of the most important fishing gears applied in the Danish fishery. Fishing gear can be divided in three groups:

- Passive or statistical fishing gear
- Semi-active fishing gears
- Active or dynamic fishing gear

Passive fishing gears, such as gill net, long line and traps, are anchored to a fixed position. The fish swims into a net or a trap and is either entangled or trapped. Semi active fishing gear is not static, but still not active in the sence that is towed over long distances. Finally active gear is towed or dragged after the fishing vessel over long distances. This group encompass varies kinds of trawl and Scottish seine. A more detailed description is outlined in the following.

A1.1 Passive fishing gear

This chapter contains a description of passive fishing gear typically applied in Danish fishery. For each gear I have addressed, how and where it is used, target fish, vessel types and effectiveness as well as environmental characteristics.

Stationary nets

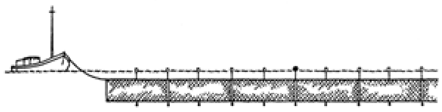
Fishery with stationary net is an old fishing method, known back to the Middle Ages fishery. Net fishery is applied for coastal fishery as well as on the ocean such as the North Sea. (Højmann, 1997)

In Denmark, there are mainly used three types of stationary nets (Muus and Nielsen, 1998):

- Drift gillnet
- Set gillnet
- Pound net

Drift gillnet and Set gillnet entangles the fish as they swim into the net. The fish are stuck in the gills, the mouth or the tale, and the mess size decides the size of the fish. In pound net fishery, the fish are trapped instead. (Muus and Nielsen, 1998; FIGIS, 2002)

Drift gill net

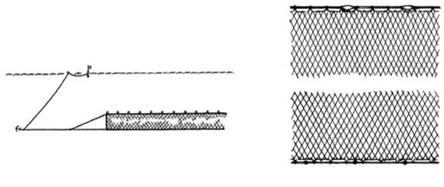


Drift gillnet is a floating net that operates on the open sea. Floaters and sinks, of lead or iron, keep the net in the correct vertical position – between the head rope and the ground rope. For setting and hauling modern vessels use mechanized haulers (FIGIS, 2002). Drift gillnet can be fixed in varies distance to the water surface depending on the target fish. The net hangs, like a curtain, suspended between a number of buoys. Drift gillnets are often attached to each other in long rows, and Salmon driftnet can be up to 20 km long. (Muus og Nielsen, 1998; Højmann, 1997)

The target fish, in Denmark, are herring, mackerel, salmon and saithe etc. (Muus and Nielsen, 1998; FIGIS, 2002)

Net vessels are usually small (<20GT) or medium sized (>20GT) and vessels larger than 100 GT, contribute only with small landings (Fiskeridirektoratet, 2001b). There are no statistics, describing the total Danish landings from vessels applying drift gillnet, because as gillnet appears as one category. However, the amounts are probably limited considering the target species. Gillnets are of special interests for small-scale fisheries because it is considered to be a low cost fishery (FIGIS, 2002).

Set gillnet



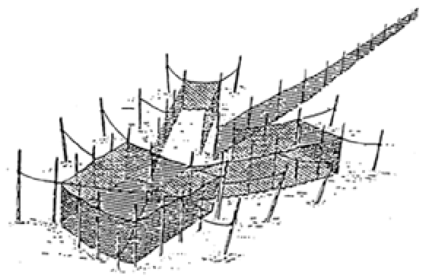
Set gillnet is based on the same principle as drift gillnet. However set gillnets are attached to the sea floor through anchors, which again are attached to buoys on the water surface. Set gillnet are also used to fish around shipwrecks and stone reefs. (Muus and Nielsen, 1998; Andersen, 1999)

The target fish, in Denmark, are normally demersal fish such as cod and flatfish (Nielsen and Muus, 1998).

Concerning vessel size and effectiveness, this fishing gear has roughly the same properties as driftnet – see above. However it could be added that considerable landings of cod (30%) and flatfish (15%) are caught by set gillnet. Opposite bottom trawl, set gill net can be used on sea floor with large piles of stones, reefs and around shipwrecks (Højmann, 1997; Appendix 2)

Pound net

A Pound net is attached to fishing stakes and consists of a net that is positioned at right angles to the coast. The net wall leads to a net trap, where the fish are trapped. This means that fish, which are swimming along the coast, are lead to the trap and caught. Pound nets are used in the coastal areas on shallow water in Denmark. (Muus and Nielsen, 1998)



The target fish is anything from Atlantic cod to Herring, European hake, Salmon and Lumpfish. The specific nets are often named after the target fish (Højmann, 1997; FIGIS, 2002).

Pound are operated by small vessels and contribute with relative small landings of cod in the Danish fishery (FIGIS, 2002; Appendix 2)

Environmental advantages - net

Gillnet and pond net generally has a low energy consumption calculated on the relationship of fuel/fish – see chapter 4 (FIGIS, 2002).

Gillnet fishery is generally very selective, both concerning target fish and size. It is a general conception that net fishery provides fish of a high quality, if the net is checked regularly and if the fish quality is sufficiently preserved after the catch. (Fiskebranchen, 1997; Miljø- og Energiministeriet, 1996; Andersen and Andersen, 1999). It has not been possible to establish the level of selectivity from pound nets.

Other advantages of gillnet and pound net fishery is that it inflicts no or only very little damage to the sea floor (FIGIS, 2002; Dorsey and Pederson, 1998; Andersen, 1999)

Environmental drawbacks - net

"Ghost" fishing, which is lost gears that continues to fish is one of the major problems in the gillnet fishery. Synthetic fibers do not rot and the gear may continue to fish for a long time after the gear is lost. It is not easy to establish a complete picture of the extension of ghost fishing, as it depends on many variables. However recent studies suggest that ghost net typically follow a certain pattern. In the first days after the gear is lost the catches decline almost exponential, as the weight of the catches causes the net to collapse. In the following weeks, scavengers eat the entangled fish, and after this initial period there follows a continuous cycle of capture, decay and attraction for as long as the net has some entanglement properties (Jennings et al. 2001). It has not been establish to how far an extend ghost fishing also apply to pond fishing, but from a theoretical point, it is reasonable to believe that the problem also exist here, at least to some extend. Fixing of nets with biodegradable material can reduce the problem (FIGIS, 2002).

By-catch of mammals and birds is another problem in net fishery (FIGIS, 2002). In the North Sea net fishery after Atlantic cod and Turbot there have been observed by-catches of porpoises. In the coastal net fishery similar problems have been observed related to by-catch of sea birds. (Lassen, 2000). Various instruments have been developed to reduce the negative impact of drift netting on the non-targeted biological resources. In 1991, the United Nations banned the use of large-scale high seas driftnets over 2.5 kilometers long. (FIGIS, 2002).

In a study of Danish Fishermens understanding of sustainable fishing practices, it is mentioned that gillnet fishery contributed with lead pollution[1], because lead is used as sinks. However this is also a problem in many other fisheries, where lead is used in sinks or lines (FIGIS, 2002; Andersen and Andersen, 1999).

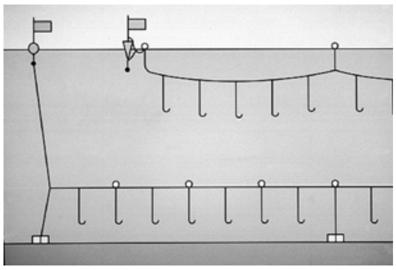
[1] In the whole Danish fishery it is estimated that the total consumption of lead is 550 tons a year. Some of the lead ends up on land and is taken care of by waste management, but some are lost together with lost fishing gear. It is estimate that 140 tons are lost at sea per year (Miljø- og Planlægningsudvalget, 2000).

Another drawback is that some fishermen use too many net, and that they stay for to long without being checked. The result is that the fish, dies and becomes unsuited or human food – which could be interpreted as a kind of ghost fishing. Finally it is mentioned that there are sometimes too many nets in one area. The latter is a barrier for fauna passage, but also a problem for other fishermen that can't get access to the fishing ground. (Andersen and Andersen, 1999)

Hooks – long lines

The most common fishing methods in Denmark are long lining, trolling and to some extent hand line. Trolling fishery is actually an active fishing method, but is described here for structural reasons.

Long line



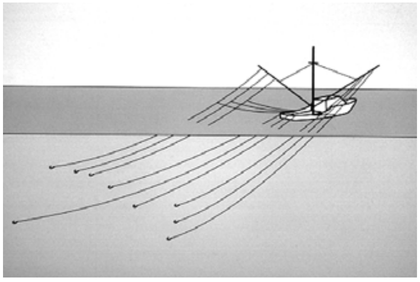
Long line fishery involves a main line that can be up to several hundreds meters, holding hundreds of branch lines with baited hooks. The size of the hooks and the distance between them decides the target fish. The lines can be set in several ways - for example near the surface for salmon fishery or near the bottom if the target fish is demersal fish, such as cod. The bait can be herring, mackerel, sandeel, octopus and mussels depending on the type of target fish. In Denmark long line fishery has been applied in Baltic Sea fishery targeting salmon for a longer period. In recent years there has been made attempts to introduce it in demersal fisheries in the North Sea fishery as well. (Fiskebranchen, 1997; Muus and Nielsen, 1998; Krog, 2001)

The target fish in Danish long line fishery is mainly codfish and salmon (Fiskeridirektoratet, 2001b; Andersen and Andersen, 1999)

Vessels applying long lines or other hook gear are usually small or medium sized, at least in Denmark. Fishing gear, involving hooks doesn't contribute significantly to the Danish fishery considering the total volume (Fiskeridirektoratet, 2001b). The technological development, have improved the effectiveness of long liners, and modern medium sized vessels have automatic line haulers as well as automatic hook handling and baiting systems. (FGIS, 2002)

Modern long liners can be very effective, and the catch, normally have a very high quality. However, one of the problems is the lacking ability to switch to other types of fisheries in a period with limited catch opportunities. (Krog, 2001)

Trolling and hand line



Apart from long line, hooks are also applied in fisheries such as Trolling fishery, where the vessels are sailing slowly forwards, while lines with hooks and bait is pulled behind the boat. This fishery is actually a active, but is described here because it is related to long line fishery. (Fiskebranchen, 1997; Muus and Niel-sen, 1998)

Another and very simple kind of hook fishery is hand line, where a hook is attached to a line, which is moved up and down, by hand or machine, to at-tract the attention of the fish. Modern machinery makes it possible to control weight and depth, to automatically move the line up and down and some machines can even take the fish off the hook (Fiskebranchen, 1997).

The target fish for trolling fishery is for example mackerel, while hand line can be used to catch many types of fish.(Muus and Nielsen, 1998)

The vessels in trolling- and hand line fishery are typically small. Just as for long line, these types of fishery contribute only of marginal importance to the Danish Fishery. (Appendix 2).

Environmental advantages - hooks

The energy consumption in long line fishery, is considered to be moder-ate/low, which is confirmed in the present study (Andersen, 1999 and An-dersen; Long line, 2001)

The amount of unwanted by-catch is generally small and the size of the hook and the bait, decides the size of the fish. In some fisheries, such as the eel hook fishery, the catch of undersized fish may appear. It must also be stressed that the quality of the fish are generally considered to be very high. (Andersen and Andersen, 1999)

Danish fishermen, mention hook fishery as one of the most environmentally sound fisheries, and the contact with the sea floor is either non existent or minimal. (Andersen and Andersen, 1999; FIGIS, 2002)

Environmental drawbacks - hooks

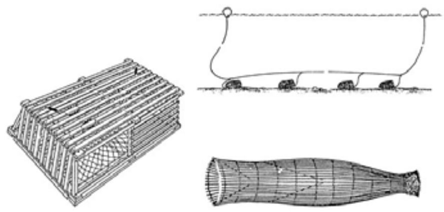
Even though fishing methods with hooks are generally described as environmentally sound there are also issues that should be addressed.

First of all, lost fishing gear may continue to fish or inflict damage to fish for a certain period, just as in the net fishery. Hooks may also damage fish that are not caught. (Jennings et al. 2001)

Furthermore the by-catch of sea birds is often mentioned as one of the most serious environmental problems in surface long lining. The sea birds can also be caught when attracted by the bait, before the hooks inter the water, but bird scaring devices, can effectively reduce this problem[2]. (Jennings et al. 2001). By-catch of undersized fish, such as cod, in the Danish eel fishery or sea birds have also appeared (Andersen and Andersen, 1999).

Finally, Danish fishermen argue that attention should also be given to the bait. In some cases Octopus is imported from Korea and other remote areas. In this regard both energy for transport, and potential problems with overexploitation should be considered. (Andersen and Andersen, 1999)

Pots and traps



Pots are round basket like devices, mainly used in lakes, rive and shallow sea water (Fiskebranchen, 1997). The same applies to traps, which can have the shape of box or barrel. Traps normally used bait and can have several entrances (FIGIS, 2002).

[2] Modern long liners, have in some cases a whole inside the ship where the lines are hauled. This prevents birds from being entangled and improves the working conditions for the crew. The crew can simply work inside the vessel. Furthermore the vessel is able to fish in more rough weather conditions.

The fishery with pots is used to target such as shrimps, eels and cod, while traps are used to catch crabs and lobster, in the Danish fishery (Fiskebrancen, 1997).

It is mainly small vessels that operate such fishing gear (FIGIS, 2002).

Environmental advantages

Little information also concerns energy consumption. Nevertheless it must be assumed that the energy consumption is relatively low, compared to active gears, which generally have a higher fuel consumption – see chapter 4. However references, which support that the fuel/fish ration is low, have not been established.

The size of the mesh, contributes to a selection, and helps the smallest individual to escape – at least to some extent. In addition escape panels can be established on one side of the pot or trap (FIGIS, 2002).

Concerning Sea floor impacts, also little information has been available, but as the gear is static, it must be assumed that the damage inflicted on the sea floor is limited.

Environmental drawbacks

Lack of information, also to some degree, applies to the environmental drawbacks. Nevertheless it can be established that by-catch and catch of undersized species can occur and may be significant in some fisheries.

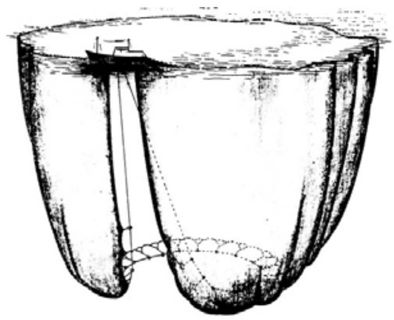
Another problem is that lost pots and cages may continue to fish for a long period of time. Pots and traps tend to be made of robust materials with a rigid structure. This means that they are likely to maintain their shape and hence continue to fish even longer than lost nets. As for lost nets, re-baiting cycles occur, which suggest that lost traps and pots may continue to fish indefinitely. Little is known about the frequency of lost pots and cages, but some studies indicate that the loss can be substantial – up to 11% per year (Jennings et al. 1999 p 268-269). Ghost fishing, with pots and cages, can be limited if at least a part of the pot/cage is made from biodegradable material (FIGIS, 2002)

A1.2 Semi-active fishing gear

I have established a category termed “semi-active” fishing gear, to describe a group of gears with the following characteristics: 1) The fishing gear is only dragged through the water in a very limited distance, 2) The time and energy use in the catching phase is limited, compared to active fishing gear. In Denmark there are two types of fishing gear that dominates this group:

- Purse seine
- Danish seine

Purse seine



Purse seine belongs to the group of encircling nets. Purse seines can be extremely large and may take entire shoals of fish. The word “Purse” comes from the mechanism that close the net, which is a lead line that is drawn closed by the purse wire that runs through a series of loops at the bottom of the net. The fish are subsequently pumped aboard the vessel. (Jennings et al. 2001). Purse seine fishery is typically conducted on the open Sea on great depths such as the North Sea. Purse seines can fish down to depths around 200 meters. (FIGIS, 2002)

The target fish is pelagic fish such as herring, mackerel and anchovies, but it can also be used to catch many other species such a tuna (FIGIS, 2002).

In Denmark Purse large vessels typically use seine. The fishing method is known as one of the most effective fishing methods, as the energy consumption is low, while the fish quality is high[3]. The fishery have been boosted by

[3] Danish fish processing industries prefers pelagic fish (herring and mackerel) from Purse seiners because the quality is generally very high compared to fish from trawl-

a technological development, which have mechanized the hauling operation and made it relatively easy to detect and encircle shoals of fish (Jennings et al. 2001)

Environmental advantages

Purse seine is very effective and the fuel consumption per catch volume is very low (Purse seine, 2001).

Purse seine in itself do not have a high selectivity, but technological equipment, which is normally installed in large purse seiners, is able to quite precisely detect the type and composition of the potential catch. If a Purse Seiner, by incident catch a shoal of undersized fish or fish that are unwanted, it is possible to let them out before hauling. Some species such as herring are quite sensible to physical damage and a few may die after this process. Only little information have been available about the extend of this problem, but unwanted catch and discard is probably a limited problem[4] in seine fishery, according to an expert in fishing gear at the North Sea center in Denmark (Hansen, 2002)

Finally purse seine normally don't have sea floor contact and therefore doesn't inflict damage to the bottom habitat (FIGIS, 2002).

Environmental draw backs

Among the negative impacts are incidental capture of dolphins in certain fishing areas. However this is not a problem of concern in the Danish Waters. Furthermore special techniques have been developed to reduce by-catch of dolphins, which allow encircled dolphins to escape alive. (FIGIS, 2002)

Purse seine may have by-catches of small fish, juveniles or endangered species. The practice of encircling floating objects, increases the capture of small sized and immature fish (FIGIS, 2002). However floating attraction devices are not used in the Danish fishery, according to my knowledge.

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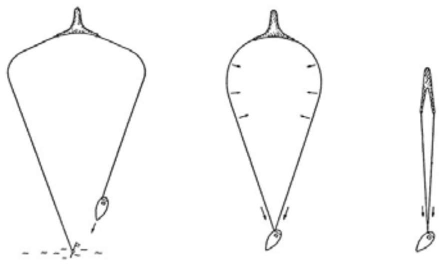
ers. However some super trawler with RSW-tanks may be able to compete (Thrane, 2000b)

[4] The fish shoals typically consist of fish with more or less the same size and the fishermen are only interested in the large fish, because it maximizes their profit (Hansen, 2002)

The effectiveness of the fishing gear is also a disadvantage in the sense that uncontrolled fishery may fish down large populations in very short time. This could be one of the reasons behind the collapse of herring stocks in the early 1970s.

Danish seine



Danish seine, also known as "anchor seine", invented in Denmark. A dragline with a net is set out from an anchored buoy. The operation is carried out directly by the main vessel, or from an additional smaller boat. Thus, a big area is encircled and the next phase is hauling, where the two draglines are simultaneously hauled with the help of a rope-coiling machine until the bag with the catch can be taken on board the vessel. (FIGIS, 2002)

Scottish seine is a variation of Danish Seine, where the vessel is sailing while hauling the net, so that a larger area is fished. This method is mainly used in Scottish fishery, but is also used in Denmark, to some extend. This fishing method may be categorized as an active fishing method.(FIGIS, 2002)

Danish Seine is mainly applied in shallow water, but is also used in banks in the North Sea. Seine nets can theoretically be applied on depths ranging from 50 to 500 meters. (FIGIS, 2002)

The vessels are typically small or medium sized vessels under 60GT. The vessels contribute with significant catches of plaice (32%) and cod (10%). The total catches are equivalent to 4% of all edible fish in the Danish Fishery. (Fiskeridirektoratet, 2001b). Compared to trawl, Danish Seine has the advantage of being able to fish in areas with rocks, because the draglines can be laid out in such a way that the rocks are avoided. (Muus and Nielsen, 2002). It must be stressed that Danish Seine lands fish of an excellent quality, partly because the fish are caught in the last part of the hauling process and partly because the towing time is small compared to trawl. (Muus and Nielsen, 1998; Jennings et al. 2001; Andersen and Andsersen, 1999)

Environmental advantages
Danish seine is energy effective and can be operated by small vessels with and little engine power. Danish seine consumes roughly the same amount of energy per catch as gill netters (Nielsen and Muus, 1998; Appendix 4).

Danish Seine has a good selectivity, because it is dragged through the water at a relatively low speed. This means that the meshes will stay open and it increases the chances for undersized fish to escape. Apart from that the catch will typically not be damaged, therefore have a greater chance to survival. (Andersen, 2002a).

Concerning effects on the sea floor, there is not much information available in the literature. However, Danish seine have a good environmental image among fishermen. Fishermen typically argue that the gear is less heavy compared to bottom and beam trawl and that the impacts on the seabed are smaller. There have been developments towards heavier draglines (45 mm), which may erode parts of the environmental advantage. (Nielsen and Muus; Andersen and Andersen, 1999).

Environmental draw backs
It is difficult to find any environmental drawbacks apart from the fact that Danish Seine has contact with the sea floor. There are no studies of the effect compared to trawl, but according to Danish Fishermen, the damage may reach the same proportions as trawl gears if the draglines have a large diameter. (Andersen and Andersen, 1999)

A1.3 Active fishing gear

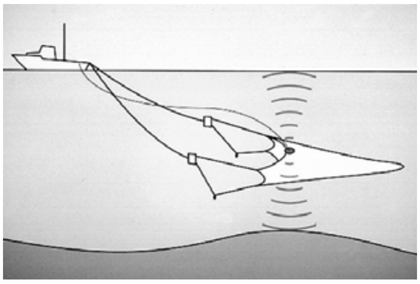
This chapter deals with active fishing methods. The gears typically applied in Denmark are all trawls, which can be divided in three groups:

- Midwater trawl - pelagic trawl
- Bottom trawl – demersal trawl
- Beam trawl - demeral trawl

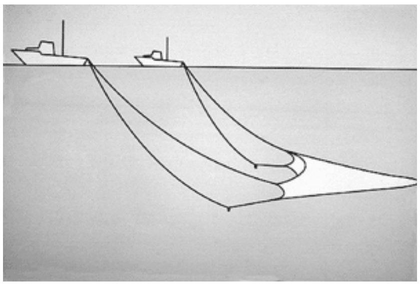
These three types of gear, can be subdivided in a long series of trawls, which are used to target specific species, just as in net fishery. Examples are 1) shrimp trawl, which is small meshed trawl fishing near the bottom, 2) industrial trawl, which is similar to shrimp trawl, but typically larger and 3) lobster trawl, characterized by a series of things such as a wire of lead, that enables to trawls to have a good contact with the sea floor (Hansen, 1986b).

Mid-water trawl (Pelagic trawl)

The trawl came to Denmark in the beginning of the 20th century and was initially introduced in demersal fisheries. After the second world war the trawl was modified to be able to fish longer up in the water column, so-called mid-water or pelagic trawl (Højmann, 1997).



There are generally two types of midwater trawl, namely midwater otter trawl (right-top) and midwater pair trawl (right-down). Midwater otter trawl is a cone-shaped net, which is towed after a fishing vessel. Otter boards maintain the horizontal opening, and the vertical opening is maintained through floats on the headline and weights on the ground line. (FIGIS, 2002)



Midwater pair trawl is basically the same, but the trawl is towed by two vessels instead of one, and the two vessels contribute to the horizontal opening in the net, instead of otter boards. One of the advantages is that it can fish close to the water surface. Herding effect, on fish by the two vessels, may also increase the capture efficiency in shallow waters and at the surface. (FIGIS, 2002)

For mid-water trawl in general, the fishing depth is usually controlled by means of a net sounder or depth recorders. Catch sensors can be installed in the codend to give information about the amount of caught fish. Sonars and fish finding equipment is a prerequisite for successful operations (FIGIS, 2002).

The target fish is pelagic fish such as herring and mackerel, but it is also used to catch other species such as Shrimps (FIGIS, 2002).

Trawls in general are very effective and contribute to more than 80 % of the total landings in the Danish fishery. Pelagic trawl (midwater trawl) contribute with significant landings of herring (~60%) and mackerel (~45%) in the Danish fishery. In both herring and mackerel fishery, pair trawl contributes with the largest part of the landings (~80%).

For trawl in general, the quality of the catch depends on the towing time, speed etc. If the catch is towed too long time, the fish can be damaged (Fiskebranchen, 1997). As for all other fishing gears, the quality also depends on the storing and freezing facilities, distance to catch area etc. Modern so-called super trawlers can land herring and mackerel of a good quality, but it still appears that the fish industry prefers fish from large purse seiners (Thrane, 2000a)

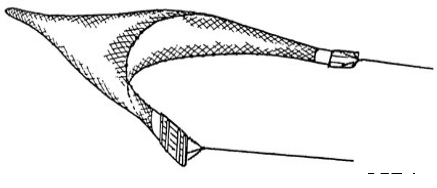
Environmental advantages
The fuel consumption per catch volume is generally low in pelagic fisheries. Pair trawl typically have a lower energy consumption than otter trawl, but still purse seine appears to be the most energy efficient fishing method for pelagic fish – see chapter 4 (Hansen, 1986 b).

Pelagic trawl has no impact on bottom habitat/structure and in most cases it is a single species fishery, where by-catch rates of other species are low. (FIGIS, 2002)

Environmental drawbacks
Incidental catch of dolphins and marine mammals may occur in some areas (FIGIS, 2002). Furthermore, it must be considered that unwanted by-catch can occur and that such catches may be discarded in some cases (Hansen, 2002). However the extend of this problem is not very well described in the literature

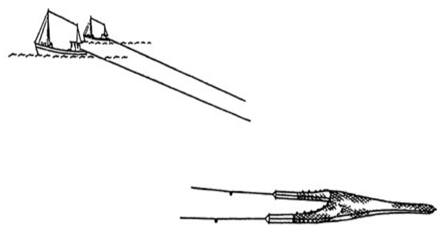
Bottom trawl

I have chosen to describe three kinds of bottom trawls used in the Danish fishery, namely bottom otter-trawl (top-right), bottom pair-trawl (second – right) and bottom twin-trawl (third -right). Beam trawl, which is also used to fish near the bottom, are described separately.

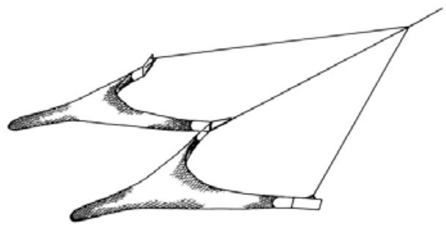


A bottom otter trawl is a cone-shaped net that is towed by one boat on the sea floor. The mouth of the trawl is held open by a headline and a ground-rope. Bottom contact with the gear is needed for successful operations, and there is often attached “tickling” chains that scares the fish up and into the net. (FIGIS, 2002)

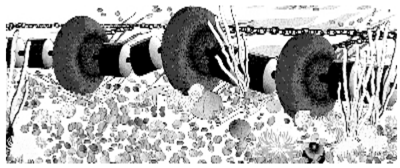
In bottom pair trawling, one trawl is towed by two boats. One of the vessels is handling the trawl and takes the catch. The other is only a towing vessel, the so-called "slave". It is a common practice to alternate the operation between the two vessels.(FIGIS, 2002)



In twin trawling one vessel tows two to four trawls. In some fisheries, such as those targeting Norway lobster and flatfish, the most important feature for effective fishery is the width of the trawl. In many cases it can therefore be an advantage to use double or triple trawls, if the engine power is sufficient. (Hansen, 1986b)



The trawls previously mentioned can be fitted with so called “bobbins” or “rock hoppers” on the ground gear. This makes it possible to fish on relatively rough grounds with stones and boulders, without getting stuck. (Muus and Nielsen, 1998).



Bottom trawls can be operated in a wide range of depths (from a few meters to 1500-2000 m), mainly at sea. They are towed across the bottom at speeds ranging from 1 to 7 knots, frequently between 3 and 5 knots. Duration of a tow can range from 15 minutes up to 10-12 hours. Typical towing time is 3-5 hours. (FIGIS, 2002)

The target species are fish living at or near the sea floor (demersal fish), for example flatfish. (FIGIS, 2002)

The vessels using bottom trawl can be everything from small vessels around 20GT to large vessels of 1000 GT or more (FIGIS, 2002). Small vessels will typically not apply twin or triple trawls. However they may use both single otter trawl and pair trawl (Hansen, 1986b)

As ealier mentioned trawl contribute with more than 80% of the total Danish fish landings. Bottom trawl caught more than 50% of the total catches of demersal fish[5] in 1999. Norway lobster nearly 100% are caught by bottom trawl. (Appendix 2)

Environmental advantages

It is difficult to find any environmental advantages from bottom trawls, as it is relative energy consuming, while inflicting damage to se sea floor. However some fishermen argue that the fish always return to the fishing grounds and that beam trawlers seem to attract more fish. Scientist has also observed this phenomenon, during research of sea floor effects, but the reason is apparently that the dead benthos that is left in the trawl path serves as food items for fish and other scavenging species in the surrounding areas. Though it may attract other fish, but it is still damaging to the eco-system. (Jennings et al. 2001).

Environmental draw-backs

The energy consumption for bottom trawl depends on a series of factors, but it is generally higher than the energy consumption for passive fishing gears. The energy consumption depends on the towing résistance that comes from the wires (2-8%), the shovels/otter boards (11-27%), towing cables and bobbins (2-24%), net (39-95%) and finally floaters (1-7%). (Hansen, 1986b)

By-catch of unwanted species can be a problem in some fisheries – especially where there is used a small mess size such as fisheries targeting shrimps and lobster. This can to some extend be mitigated by using larger meshes in the cod ends and devices in the trawl that reduce capture of small and unwanted organisms. (FIGIS, 2002)

Bottom trawls interact with the bottom sediment and may cause removal or damage of living organisms (including seaweed and corals) and displacement of stones etc. On flat sandy/muddy bottom the sediments might be whirled up into the water masses and suspended. (FIGIS, 2002)

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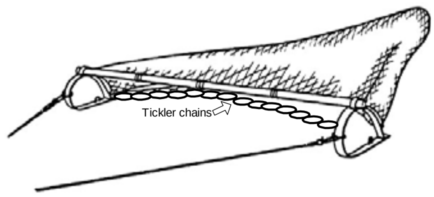
[5] Here, demersal fish cover codfish, flatfish prawn and shrimps. Blue mussels, mackerel, herring and industrial fish are not included.

Trawls fitted with large rock hoppers, can fish in areas with stones and boulders. Among some Danish fishermen there is a concern that these types of fishing gear, enter new areas, that have not been exposed to bottom tending fishing gear before. (Andersen and Andersen, 1999)

Beam trawl



In Beam trawl the horizontal opening is ensured by a beam and shovels are not required. Beam trawls are often equipped with heavy tickler chains to disturb the fish from the seabed. For operations on very rough fishing grounds beam trawls can be equipped with chain matrices, to prevent boulders/stones from being caught. The heaviest trawls are used in flatfish fishery, while shrimp beam trawls are lighter. Close bottom contact is necessary for successful operation. While targeting flatfish the beam trawls are towed with up to seven knots, which is one of the reasons why the gear needs to be heavy. The largest gears weight up to 10 tons. (FIGIS, 2002).

Beam trawl is normally used in shallower depth less than 100 meters (FIGIS, 2002). In Denmark there operates only few beam trawlers in the North sea and the are not allowed to fish in the inner Danish waters. Beam trawling is very popular in Holland, but some have recently been substituted with twin or triple bottom trawls that are supposed to be more fuel efficient (Krog, 2001).

Beam trawlers target demersal fish, mainly flatfish such as plaice. However they are also used to target shrimps and lobster etc.

Beam trawlers are often specialized medium size vessels; equipped with powerful engines arranged with large outriggers that tow two parallel beam trawls (FIGIS, 2002). The advantage of beam trawls compared to Danish Seine, which is also used to target flatfish, is that beam trawl can catch the fish during the winter as well, which is because of the high bottom contact (Jespersen, 2001)

Environmental advantages

It is difficult to find any environmental advantages for beam trawlers. However some fishermen argue that it doesn’t due much damage and that the fish returns to the fished areas year after year – see further explanation under bottom trawl.

Environmental drawbacks

Beam trawl fishery is known to have high fuel consumption per catch volume. As described in chapter 4, a Danish beam trawler has a fuel consumption in the range of 2-3 liter of fuel per kg caught flatfish. This is considerably more than Danish seine, which can catch the same species, with a fuel consumption that is a factor 10-15 lower.

Beam trawl may have considerable amounts of unwanted by-catch, but recent Danish studies indicates that the discard from beam trawlers are of the same size as other bottom dragged fishing gear. (FIGIS, 2002; Chapter 3). However it should be stressed that beam trawl is known to generate considerable amounts of discard in the form benthos, which are caught, but also benthos that are left damaged or dead in the trawl path - see chapter 4 and 10.

It is worth to notice that beam trawls induce considerable physical impact on the seabed. Among the effects are reduced biodiversity, with a higher number of short-lived organisms. Among the other effects is re-suspension of bottom sediment, soothing of bottom sediment, removal of stones and boulders. (Jennings et al. 2001; see also chapter 4 and 10)

The penetration depth varies between 1 and 8 cm depending on the sediment and beam trawls leave detectable marks on the seabed, which remain visible for up till 6 days.(FIGIS, 2002). According to Jennings et al. (2001) large beam trawls can be fitted with over 20 tickler chains and can penetrate soft sand to a depth of over 6 cm.

Scottish Seine and Trolling

As earlier mentioned Trolling fishery and Scottish seine also belongs to the group of active fishing methods. These fishing methods are described under fishery with hooks and Danish seine.

A1.4 Final comments

Active fishing gear

There is a series things that point towards active fishing gear as the most damaging to the environment. The impacts include high fuel consumption and damage to the sea floor and the organisms that lives there.

Passive and semi active gear

Passive and semi active fishing gear, have generally a low energy consumption, and has no or at least very limited impacts on the sea floor. However, two problems that mainly addresses passive fishing gear (gillnet) is 1) ghost fishing and 2) by-catch of marine mammal and sea birds. Besides it is argued that net fishery can act as a fauna barrier.

Passive fishing gear has many advantages and the quality of the fish that are caught is often described as better than for active fishing gear. However, for some of the gears, such as long lining, the disadvantage is that they are difficult to adjust to new types of fisheries. This means that they may get into problems, economic wise, if the quota of the target fish is shrinking during the year.

Sometimes it is also mentioned that passive or semi active fishing methods (except purse seine) only contribute with relatively small amounts of fish. Some people from the fish industry argues that Denmark have to many old and small fishing vessels. They would prefer fewer, newer and larger vessels, which are able to supply the industry with stable amounts of fish all year round and of a given quality (Thrane, 2000b).

There are many environmental aspects that should be considered when comparing different fishing gear, and in some cases it is difficult to make any decisive conclusions about what fishing gear is better. If we also consider economical and social aspects it becomes even more complex. However, this should not be seen as an excuse for avoiding further analysis of strengths and limitations for different fishing gear.

Acknowledging, that it implies great simplifications and uncertainties, I have tried to make a matrix that shows some of the strengths and weaknesses for different groups of fishing gear. The intention is not to be able to reach a decisive conclusion about what is best, but to elucidate the complexity of the area and some of the tradeoffs that necessarily has to be made between environmental, social and economical aspects.

In the following table it assumed that the passive fishing gears as well as Danish seine are operated by relatively small vessels, while purse seine and trawl are operated by relatively larger vessels – which reflects the composition of the Danish fishing Fleet (Fiskeridirektoratet, 2001b)

Table 1: *Tentative estimate of potential environmental impacts from three main groups of fishing gear used in the Danish Fishery. (+) means good, (o) means average or not estimated, (-) means poor*

		Passive	Semi active		Active	
	Type of impact	**Gillnet and hook**	**Danish Seine**	**Purse seine**	**Mid-water trawl**	**Bottom trawl**
Ecology	Fuel consumption	+	+	+	O	-
	Selectivity of fish	+	+	O	O	O
	By-catch birds/mam.	-	+	+	+	+
	By-catch of benthos	+	O	+	+	-
	Ghost netting	-	+	+	+	+
	Fauna barrier	-	+	+	+	+
	Sea floor damage	+	O	+	+	-
	H & S	O	O	O	O	O
Econ	Quality of catch	+	+	+	O	O
	Adaptation to quota[6]	O	O	O	O	+
	Demands from industry	O	O	+	O	+
Soc.	Tourism (atmosphere)	+	+	-	O	O
	Employment fishery	+	+	-	-	-
	Employment industry	O	O	+	O	+

Again it should be stressed that the table only presents a very rough assessment, and that a separate dissertation focusing on only these aspects would be required to generate a more sound analysis.

[6] "Adaptation to quota" means the ability to adapt to other target species in other areas according to the changing patterns in the fish resource, mobility etc. Trawl is especially strong here because trawl can be used in many areas and to many species. Furthermore a trawler can easily adapt to other kinds of trawl gear. Some Danish purse seiners are combined seiners and trawlers. This provides excellent possibilities to adopt to the fish resource.

App. 2: Catches by Vessel & Gear

This appendix provides information about fishing methods applied to catch different species in the Danish fishery. The information has been established in co-operation with the Danish Fishery Directorate during 2001.

A2.1 Catches by different fishing gear

There is applied different sizes of vessels to catch varies kinds of target species. Considering the whole Danish fishery, it is possible to describe how much of different species that are caught by different fishing gear (Table 1):

Table 1. *Fishing methods used for the most important groups of species in Danish Fishery in 1999. Data are based on the fishermen's estimates on the time of catch*[7]*. Bold figures are the most important fishing methods in each species category (Fiskeridirektoratet, 2001b).*

		Demersal		**Shell**			**Pelagic**		**Indus-trial fish**
	Fishing gear	Atlantic Cod	Flatfish	Norway lobster	Prawn/ shrimp	Mus-sels	Herring	Mackerel	
	Unspecified	0,1	0,1	1,9	36,6	0,0	0,0	0,0	0,0
Passive	Hooks/ lines	0,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Traps etc.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Pound net	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Gill net	**28,7**	**12,3**	0,1	0,0	0,2	0,1	0,0	0,0
	Purse seine	0,0	0,0	0,0	0,0	0,0	**37,2**	**55,6**	0,0
	Danish seine	**9,6**	**28,9**	0,0	0,0	0,0	0,0	0,0	0,0
Active	Dredge etc	0,6	0,0	0,0	0,0	**96,4**	0,0	0,0	0,0
	Pair trawl	**9,6**	0,5	0,4	0,5	0,0	**51,4**	**33,8**	0,0
	Trawl	**49,4**	**41,6**	**96,9**	**41,3**	0,1	**10,6**	**10,5**	**100,0**
	Beam trawl	0,5	**14,6**	0,0	**19,4**	0,0	0,0	0,0	0,0
	Other	0,6	1,9	0,7	2,1	3,3	0,6	0,0	0,0
	All	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
	Absolute (1000 ton)	53	27	5	12	159	138	31	1008

The total catch, estimated by the fishermen is 1.432.000 ton (Fiskeridirektoratet, 2001b).

As it appears trawl is one of the most widespread fishing methods. However the table only distinguishes between a few kinds of trawl and not between bottom trawl and mid-water trawl. However it must be assumed that nearly all demersal and shellfish are caught by bottom trawl, while herring anmack-

[7] It should be mentioned that "other codfish" are left out. The amount of other codfish is app. 10.000 tons equal to roughly 20 % of the catches of Atlantic cod. Compared to the official catch statistic, the amount of Atlantic cod is underestimated with nearly 30 % and blue mussels are overestimated with roughly 50%. For industrial fish, I have used figures for landings instead of catches, because the figures for total catches were unrealistically high, in the data I got from the Fishery Directorate. Industrial fish are not gutted on the sea, and I therefore assumed that the landings reflected the catches, to a large extend. The table is therefore not 100 % accurate, but it provides a somewhat reasonable picture of the fishing methods (Fiskeridirektoratet, 2000; Fiskeridirektoratet, 2001b)

erel are caught with mid-water trawl. For industrial fish, it is also assumed that bottom trawl is the most used fishing gear in the trawl category (See app. 1).

Trawl contributed with a total of 81 percent of all catches in 1999. If mussel dredge is also considered a trawl - trawl amounted to 92% of the total catches in 1999. Only considering the catches of edible fish (all fish except industrial fish and mussels) trawl contributed to 60% of the catches. The same percentage is reached if we look at demersal fish and shellfish.

In other words, other fishing gears are also important when we focus on the most valuable fish species. Among the most important other fishing gears are gill net, purse seine and Danish seine. Considering all catches of edible fish excl. mussels, gill net contributed with 7%, Purse seine (26%) and Danish seine (5%) in 1999. If we only look at catches of demersal and shellfish excl. mussels gill net contributed with 19%, while Danish seine contributed with 13 %.

A2.2 Catches by vessel sizes

It is also possible to determine how much fish that are caught by different vessel sizes. Table 2, shows that the average size of the vessels in each species category varies, significantly.

Table 2. *Fishing vessels used for the most important groups of species in Danish Fishery in 1999. Data are based on the fishermen's estimates on the time of catch. Shortcomings and uncertainties are explained in the footnote o the previous table for fishing gear. (Fiskeridirektoratet, 2001b)*

	Demersal		**Shell**			**Pelagic**		**Indus-trial fish**
Fishing gear	Atlantic Cod	Flatfish	Norway lobster	Prawn/ shrimp	Mus-sels	Herring	Mackerel	
Unknown	0,0	0,0	2,3	36,8	0,0	0,0	0,0	0,0
0-5.9	0,8	0,5	0,0	0,0	5,9	0,1	0,0	0,0
6-9.9	3,9	2,3	0,3	0,0	25,7	1,2	0,0	0,2
10-14.9	7,8	6,1	2,8	0,0	23,2	1,4	0,0	0,2
15-19.9	34,1	23,7	12,6	4,7	16,6	8,9	0,0	0,9
20-39.9	13,4	16,3	15,6	6,8	10,6	1,5	0,0	1,1
40-59.9	20,9	17,1	14,1	6,0	6,8	2,9	0,0	2,5
60-79.9	5,5	4,6	7,8	6,6	9,8	0,2	0,0	1,0
80-99.9	1,7	1,3	2,6	1,8	0,0	0,0	0,0	0,3
100-149.9	3,5	6,7	8,8	6,2	0,0	2,2	0,0	0,8
150-249.9	6,6	12,6	18,1	14,3	0,0	14,7	4,6	16,6
250-499.9	1,3	8,8	1,9	0,9	0,0	30,1	39,9	60,6
500-999.9	0,6	0,0	13,1	16,1	1,4	22,9	38,8	13,2
1000-	0,0	0,0	0,0	0,0	0,0	13,8	16,5	2,7
All	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Av. Size (GT)	**25,0**	**41,0**	**69,0**	**147,0**	**14,0**	**390,0**	**568,0**	**359,0**
Absolute (1000 ton)	53	27	5	12	159	138	31	1008

As it appears the average vessel size in each category varies between 14 GT for mussels and 568 GT for mackerel. Large vessels catch especially the pelagic species, herring and mackerel as well as indutrial fish. Relateively small vessels catch demersal fish, such as cod and flatfish, while prawn/shrimps and Norway lobster are caught by middle size vessels around 100 GT.

App. 3: Product Spillage

This appendix describes the product spillage in different stages of the product chain. Special attention is given to filet yields, which is the amount of fish filet that typically is provided per kg caught fish, before it is gutted. These data are based on an analysis carried out by Peter H. Tyedmers, which was part of his Ph.D thesis (Tyedmers, 2000). The data are obtained by a range of different sources and represents the mean values from the various sources.

A3.1 Fish spillage in the product chain

The purpose of this section is to provide an overview of the product spillage at different stages of the product chain for varies fish species.

The first spillage happened in the fishery in the form of guts that are discarded. However this only applies to demersal- and shellfish. Pelagic species and industrial fish are not gutted in the vessel.

The next spillage happens in the processing industry where by-products, which includes guts for pelagic fish are used to produce mince, fish meal and oil, mink fodder etc. It can be discussed whether this can be described as spillage or valuable by-products.

It is assumed that the spillage during wholesale and transport is insignificant but data provided by Company Flatfish (2003b) suggest that the product spillage at the retail stage is up 0,1-0,2 %. For fresh products, the amount of waste in retail may be considerably larger, but there have not been reliable data available to describe this further.

Finally, there is the food spillage at the consumer stage. For fish that is prepared as whole fish in the consumer stage – the amount of spillage will be of similar magnitude as the amount of by-products and fish waste in the processing stage.

Table 1 shows the spillage at different life cycle stages for a range or fish products. The end products are plain fish filet / fish meat in all cases. Thus, there is not performed any additional processing.

***Table 1:** Fish waste/by-products arising at different stages of the fish products life cycle. All figures are per kg.*

	Demersal fish		**Shellfish**			**Pelagic fish**	
Fish/fish waste	**Codfish [kg]**	**Flatfish [kg]**	**Pra./shri. [kg]**	**Lobster [kg]**	**Mussels [kg]**	**Herring [kg]**	**Mack. [kg]**
Caught fish[8]	3,149	3,149	3,674	4,322	12,870	2,396	2,204
Spillage fishery (guts)[9]	0,480	0,150	0,000	3,024	0,000	0,000	0,000
Landed (to industry)	2,669	2,999	3,674	1,298	12,870	2,396	2,204
By-products processing[10]	1,567	1,897	2,572	0,196	11,80	1,294	1,102
Sold to retail	1,102	1,102	1,102	1,102	1,102	1,102	1,102
Spillage in retail[11]	0,002	0,002	0,002	0,002	0,002	0,002	0,002
Sold to consumer	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Consumer spillage[12]	0,100	0,100	0,100	0,100	0,100	0,100	0,100
Consumed fish meat	1,000	1,000	1,000	1,000	1,000	1,000	1,000

As the data indicates it requires considerable amounts of caught fish to provide a serving of one kg fish meat/filet that is consumed. For certain products and production units there may be considerable discrepancies from the

[8] For codfish, flatfish, prawn and shrimp, herring and mackerel this number is simply the amount of served fish (-filet), divided with the filet yield. The filet yield for cod and flatfish is 0,35. For prawn and shrimp it is 0,3 and for herring and mackerel it is respectively 0,46 and 0,5 – see the following sections. The filet yield for Norway lobster it is the conversion factor between whole lobster and lobster tail (3,33) divided with the meat content of lobster tails that is estimated to be 0,85. Thus, the filet/meta yield is 3,92 for Norway lobster. For blue mussels all figures are derived from a LCA case study of blue mussels (Andersen et al. 2000).

[9] This is calculated as the difference between caught and landed fish. The difference is reflected in conversion factors established by Fiskeridirektoratet (2001a). For cod and flatfish it is respectively 1,18 and 1,05. For Norway lobster tails it is 3,33. Prawn, shrimp, mussels, herring and mackerel are not gutted before landing.

[10] The amount of by-products or fish waste related to processing (filleting or peeling) in the industry or at home varies. This is further in the following sections

[11] This number is based on information from the transport manager in a large fish processing company and only applies to frozen flatfish. However, it is used as a best estimate for other products as well (Company flatfish, 2003b)

[12] This is estimated on the basis of food loss in professional kitchens (Green Network, 2002) as well as estimates in Weidema and Mortensen (1996a)

data provided here. The high level of by-products from mussel production is related to sand and stones (50%) as well as mussel shells (50%).

A3.2 Filet and protein yields - demersal fish

Filet and protein yields for demersal fish are described in the following.

Codfish

The Danish landings of codfish mainly consist of Atlantic cod, which constitutes 86% of the total landing volume in Danish Harbors in year 2000. Other important cod species are pollack and haddock, which represent 6 % and 5 %, respectively. These three species represents 97 % of the landings (Fiskeridirektoratet, 2001a).

Table 2: *The proportion of codfish landings from Danish fishermen, as well as the maximal edible content, mean filet yield and mean protein yield of the three most important codfish species in Danish fisheries (Fiskeridirektoratet, 2001a; Tyedmers, 2000a)*

	Percentage of all Danish codfish landings [pct.]	Maximal edible meat content of whole fish [pct.]	Mean filet yield of whole fish [pct.]	Mean protein yield of whole fish [pct.]
Atlantic cod	86	50	34	18
Pollack	6	52	34	18
Haddock	5	49	35	18
Weighted average		50	34	18

As illustrated it is maximum half of the codfish, which is meat in average. Furthermore the percentage of filet that is actually used directly for human consumption only constitutes 34 % of the whole codfish in average. There are only small variations between the different codfish species.

In this respect it is also worth to mention the reduction factors from catch to landing. When calculating the nominal catch, the landed quantities are converted to live weight. The typical conversion factors are:

- Atlantic Cod or other codfish, gutted, head on: 1.18
- Atlantic Cod, gutted, head off : 1.60

This means that Atlantic cod and other codfish is reduced to 85% (1/1,18) when gutted and further reduced to 63% (1/1,60) of the catch weight if it is both gutted and de-headed (Fiskeridirektoratet, 2001a).

Flatfish

The Danish landings of flatfish mainly consist of European Plaice, which constituted 63% of the total landing volume in Danish Harbors in year 2000. Other important flatfish species are European flounder (13%), common dab and witch flounder (12%) as well as Lemon sole and Common sole (9%). All in all these species represents 97 % of the landings (Fiskeridirektoratet, 2001a).

Table 3: *The proportion of flatfish landings from Danish fishermen, as well as the maximal edible content, mean filet yield and mean protein yield of the three most important flatfish species in Danish fisheries (Fiskeridirektoratet, 2001a; Tyedmers, 2000a)*

	Percentage of all Danish flatfish landings [pct.]	Maximal edible meat content of whole fish [pct.]	Mean filet yield of whole fish [pct.]	Mean protein yield of whole fish [pct.]
European Plaice	63	52	34	16,9
European flounder	13	48	32	16,8
Common dab / witch flounder	12	44/-	23/-	16,1/17,7
Lemon and common sole	9	-	35/35	17,4/18,1
Weighted average		50[13]	32[14]	17

As illustrated it is also maximum half of the flatfish that consist of meat. The percentage of filet that is actually used directly for human consumption also constitutes 34 % of the caught flatfish in average. There are some variations between the different flatfish, and especially common dab has a low percentage of mean filet yields of the whole fish. However flatfish are similar to

[13] Here it is assumed that witch flounder, lemon- and common sole has the same maximal edible content as common dab, namely 44%.
[14] Here it is assumed that witch flounder have the same mean filet yield as common dab.

codfish for almost all the parameters. The reduction factor from catch to landing for flatfish is:

- European Plaice or other flatfish, gutted: 1.05

This means that Plaice and other flatfish are reduced to 95% (1/1,05) when gutted. As flatfish are very seldom de-headed this is not an issue here.

A3.3 Filet and protein yields for shellfish

Shrimps

The Danish landings of shrimps mainly consist of Northern prawn and Common shrimp, which constitutes 57% and 37% of the total landing volume from Danish fishermen, respectively. More precisely, these two species represents 94 % of the Danish landings of shrimps – here defined as all shellfish excl. lobster, mussels and other mollusks (Fiskeridirektoratet, 2001a).

Table 4: *The proportion of shrimp landings from Danish fishermen, as well as the maximal edible content, mean filet yield and mean protein yield of the two most important shrimp species in Danish fisheries (Fiskeridirektoratet, 2001a; Tyedmers, 2000a)*

	Percentage of all Danish shrimp landings [pct.]	Maximal edible meat content of whole shrimp [pct.]	Mean filet yield of whole shrimp [pct.]	Mean protein yield of whole shrimp [pct.]
Northern prawn	57	36	-	16,8
Common shrimp	37	-	-	19,5
Weighted average		36[15]	-	17,9

As illustrated it is only around one third of the shrimps that consist of meat.

[15] There are no data available for common shrimps, and it is therefore assumed that the maximal edible meat content is the same as for Northern prawn

Norway lobster
There are only few data concerning Norway lobster. It has not been possible to estimate to maximal edible meat content in Norway lobster, nor the protein content. However, the Danish authorities uses a conversion factor between landed quantities and live weight, which is 3,33 for the tails (Fiskeridirektoratet, 2001a). This means that the lobster is reduced to 30 % (1/3,33) of its live weight when only the tail remains. The meat content is further reduced when the shell is removed, but it has not been possible to establish how much. Therefore, I have used a 0,3 as the best possible factor for the yield.

A3.4 Filet and protein yields for pelagic fish

Mackerel
The Danish landings of mackerel Atlantic mackerel, which constitutes 16% of the total landing volume of mackerel and herring in Danish Harbors in year 2000 (Fiskeridirektoratet, 2001a).

Table 5: *The maximal edible content, mean filet yield and mean protein yield of Atlantic mackerel (Fiskeridirektoratet, 2001a; Tyedmers, 2000a)*

	Maximal edible meat content of whole fish [pct.]	**Mean filet yield of whole fish [pct.]**	**Mean protein yield of whole fish [pct.]**
Atlantic mackerel	61	54	20,1

Compared to cod- and flatfish mackerel actually has a higher maximum meat content. Furthermore the percentage of filet is quite high in average, namely 54 % of the whole fish. As mackerel are typically landed without any previous processing, there are no conversion factors between catch and landings.

Other sources such as Miljøstyrelsen (2004) suggest that the filet yield is 50%. The same sources stress that the yield is further reduced when the filet is put into cans that are sterilized. It is suggested that the final yield is 42-43%. However, it should be noticed that this reduction is only because the water content in the meat is reduced.

Herring

The Danish landings of mackerel Atlantic mackerel, which constitutes 16% of the total landing volume of mackerel and herring in Danish Harbors in year 2000 (Fiskeridirektoratet, 2001a).

Table 6: *The maximal edible content, mean filet yield and mean protein yield of Atlantic herring (Fiskeridirektoratet, 2001a; Tyedmers, 2000a)*

	Maximal edible meat content of whole fish [pct.]	Mean filet yield of whole fish [pct.]	Mean protein yield of whole fish [pct.]
Atlantic herring	61	46	18,4

As the table points out the mean filet yield is 46%. Compared to cod- and flatfish herring also has a higher maximum meat content. Other sources suggest that the average filet yield of pickled herring is 0,43% before storing in glass or bucket. However, this is probably because of water loss in the storing process. Before the marinated herring is stored in the consumer packaging the filets are trimmed and sometimes de-skinned. The yield may therefore end up being around 40% or even lower (Andersen et al. 1996).

Industrial fish

The Danish landings of industrial fish consist of Sandeel (53%), and European sprat (26%) and Norway pout (14%) of the total volume landed by Danish Fishermen in Danish Harbors (Fiskeridirektoratet, 2001a). All in all these three species constitutes 93% of the total landing volume of industrial fish from Danish fishermen in Danish harbors.

However as these species are not used directly for human consumption it has not difficult to find data about the meat content, filet and protein yield. However there exist data on European sprat, which is regarded as edible fish in some.

Table 7: *The proportions between landings of industrial fish from Danish fishermen, as well as the maximal edible content, mean filet yield and mean protein yield of these species (Fiskeridirektoratet, 2001a; Tyedmers, 2000a)*

	Percentage of all Danish industrial fish landing [pct.]	Maximal edible meat content of whole fish [pct.]	Mean filet yield of whole fish [pct.]	Mean protein yield of whole fish [pct.]
Sandeel	53	-	-	-
European sprat	26	56	50	17,7
Norway pout	14	-	-	-

As there are only data available for European sprat it is has not been possible to say something general about industrial fish. However, the figures shows that it is possible to get reasonable quantities of meat and filet from certain species of industrial fish.

App. 4: Data Quality Assessment

The data quality assessment is based five indicators directly adopted from Weidema (1998).

Indicators in the data quality matrix

Three indicators are related to the scope of study while two are related to data reliability and completeness. The latter two are absolute indicators, while the first three are relative to the goal for data quality.

- Time correlation (Ti) expresses the degree of accordance between the year of the study, as described in the data quality goals, and the year of data collection.
- Geographical correlation (Ge) expresses the degree of accordance between the production conditions in the area relevant for the study, and in the geographical area covered by the obtained data.
- Technological correlation (Te) refers to all other aspects of correlation. Although data may be of the desired age and representative of the desired geographical area, they may not be representative for the specific enterprises, processes, or materials under study.
- Data reliability (Re) reflects the acquisition methods and verification procedures. In this study verification only includes comparisons to data from other studies.
- Completeness (Co) reflects whether parts of data are missing as well as the statistical representativeness of the data.

The semi-quantitative assessment

In each category there is used a number between 1 and 5 to describe the degree of correlation or the level of reliability and completeness. Small numbers refers to high correlation or data quality – se table 1.

__Table 1.__ Data quality assessment matrix, adopted from Weidema (1998).

	1	2	3	4	5
Level of Reli-ability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified esti-mate (e.g. by industrial expert)	Non-qualified estimate or unknown origin
Level of Complete-ness	Representative data from a sufficient sam-ple of sites over an ade-quate period to even out normal fluctua-tions	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representative-ness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Time (scope) Correlation	Less than 3 years of dif-ference to year of study	Less than 6 years of differ-ence	Less than 10 years of dif-ference	Less than 15 years of differ-ence	Age of data un-known or more than 15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production condi-tions	Data from area with slightly similar produc-tion conditions	Data from un-known area or area with very different produc-tion conditions
Technological correlation	Data from enterprises, processes and materials under study	Data from proc-esses and mate-rials under study but from different enterprises	Data from proc-esses and mate-rials under study but from different technology	Data on related processes or materials but from same tech-nology	Unknown tech-nology or data on related proc-esses or materi-als, but from different technol-ogy

The scores are "semi-quantitative". They serve as identification numbers only, and do not represent a certain "amount" of data quality. The numbers must not be compared across indicators, nor should they be regarded as equidistant. For instance a score of four is not necessarily twice as problematic as a score 2 on the same indicator. For the same reasons the numbers should not be added or aggregated.

Consistent use – independent variables

To ensure a consistent use of the indicators, it is important that the five indicators are regarded as mutually independent. This means that the reliability score can be very low even though the completeness is high. This could be the case if the data are based on a broad study covering many companies, but where the estimates in each case are based on expert assumptions that are not verified. Also, the data may be from a different country, which gives a low score in geographical correlation, but the same data may represent the same type of processes or materials and therefore have a high score in technological correlation. (Weidema, 1998).

Similarly, the indicator "Completeness" may indicate perfect representativeness even when the three correlation indicators show a very bad correlation. This is because the representativeness is not relating to the study in which the data is being used, but only to the data itself. A set of data may be completely representative of the U.K. situation in 1976, but still has a very bad correlation if the study is on French industry in 1995. On the other hand, a perfectly fitting up-to-date set of data from the enterprise under study may not be complete.

App. 5: Energy & Species (fishery)

This appendix contains information about energy consumption for nine different fish species. The first section 5.1 describes the fishery categories and should be seen as the basis for the calculation of fuel consumption for the fish species – section 5.2 to 5.10. Section 5.11 includes an overview of the results for all nine fish species. All sections follow the structure generally applied for descriptions in this dissertation:

1) Process description
2) Data collection and treatment
3) Scope
4) Results
5) Validation and representativeness

Each of the sections from 5.2 to 5.10 can be seen as separate data sheet, and have originally been designed for a database concerning LCA data on food products in Denmark - see www.lcafood.dk.

Several of the numbers and figures that are presented in this appendix, refers to excel files that are available on the CD – see app. 5 document C.

A5.1 Fishery categories

This section contains basic information about the fishing categories that have been the basis for calculation of fuel consumption for the specie groups.

Process description

Processes included and product flow is described separately for the nine species in section 5.2 - 5.10.

Data collection and treatment

Data sources

The data for catches and fuel consumption, mentioned in previous section, are based on fishermen's records and have been collected by the Danish Institute for Food Economics. In cases where the exact figure for fuel consumption has not been available, the fuel consumption has been estimated by dividing the fuel costs with the average price for fuel. For further details see Fødevareøkonomisk Institut (2001b).

The adjustments in fuel consumptions have been possible through additional datasets for fuel consumption for "clean fisheries" targeting only herring, -mackerel, -shrimp and -blue mussels.

Data for clean fisheries of herring and mackerel have been established based on interviews covering 5 modern trawlers (Pelagic trawl, 2001) and 3 purse seiners (Purse seine, 2001) covering the calendar year 2000. For both vessel categories, it has been possible to establish the exact fuel consumption in periods with either herring fishery or mackerel fishery. Data have been available through accounts covering fuel and catches.

Separate records of the energy consumption in clean shrimp and mussel fishery have determined exchanges associated specifically with mussel fishery. These records cover 6 concerns in both cases. (Nielsen, 2002b).

The original seven fishing categories

The Danish Institute for food economics subdivides the Danish fishery in 7 fishing categories. The definitions of each category as well as the geographical location of main fishing sites are shown in Table 1. Numbers, names and definitions are based on Fiskeriøkonomisk Institut (2001b)

Table 1: *Characteristics of seven distinct fishing categories, based on 1) Fødevareøkonomisk Institut (2001b) and 2) Fiskeridirektoratet (2001a).*

Fishing category		Definition[1)]	Geographical location of main fishing sites[2)]
	Name		
1	Atlantic cod fishery	Atlantic cod makes up more than 2/3 of the total SCV[16]	Eastern Baltic and the North Sea
2	Atlantic cod, European plaice and Common sole fishery	Atlantic cod, European plaice and Common sole make up more than more than 2/3 of the total SCV although neither Atlantic cod nor flatfishes comprise more than 2/3 of the total SCV	North Sea, Skagerak, Kattegat, the belt seas, the sound as well as west and east Baltics
3	Flatfish fishery	Flatfish make up more than 2/3 of the total SCV	Widely spread over the Danish Sea territory.
4	Norway lobster, codfish and flatfish fishery	More than 2/3 of the total SCV come from Norway lobster, codfishes and flatfishes, where Norway lobster comprises more than 1/3 of the total SCV and more than both codfishes and flatfishes each	Skagerak and Kattegat
5	Herring, mackerel and industrial fish	More than 2/3 of the total SCV come from herring, mackerel and fish for reduction (industrial fish), but fish for reduction comprises less than 2/3 of total SCV.	North Sea, Skagerak as well as the sound and the Eastern Baltics
6	Industrial fish (fish for reduction)	More than 2/3 of the total SCV comes from fish for reduction	North Sea
7	Mixed fishery	Specialized fisheries targeting eels, blue mussels, common shrimp, northern prawn and other	Eels: the sound and the Baltic. Blue mussels: Limfjorden. Common shrimp: North Sea and Skagerak Northern Prawn: North Sea

The number of vessels, the average size, fuel consumption as well as catches per vessel for the different fishing categories is illustrated in table 2.

[16] SCV means Standard Catch Value and is a measure of the standard average value for a given year for a given species according to the Danish Research Institute for Food Economics.

Table 2: *Energy, catch and vessel data for the 7 fishing categories (Fødevareøkonomisk Institut, 2002b)*

Fishing Category	**No. 1**	**No. 2**	**No. 3**	**No. 4**	**No. 5**	**No. 6**	**No. 7**
	Codfish	Codfish/ flatfish	Flatfish	Norway Lobster	Pelagic	Industrial fish	Mixed fish
Number of vessels (units)	370	244	175	182	23	96	438
Fuel per vessel (1000 liter)	37	41	103	158	845	556	123
	Catches (kg)						
Codfish	68.779	50.328	13.943	30.128	19.595	11.259	37.763
Flatfish	7.979	30.851	83.469	16.870	189	2.952	18.767
Norway lobster	136	164	57	19.648	257	102	3.088
Herring/ mackerel	14.576	199	2	3.382	3.980.377	250.161	108.700
Industrial fish	6.367	23.552	6.571	17.199	4.305.760	8.265.482	485.861
Mixed	31	338	119	8.677	36	1.380	265.318
Other edible fish	844	977	1.710	5.270	81	713	14.316

By multiplying the number of vessels with the catches in each category, the total catches can be estimated to 1.518.561 tons, which is close to the figure from the official statistic of 1.534.000 ton (Fiskeridirektoratet, 2001b)

Adjustments to fishing categories (from seven to nine categories)

The original structure of fishing categories provided by Fødevareøkonomisk Institut (2002b) has been adjusted slightly to provide accurate data on most possible species. As co-product allocation is handled by means of system expansion, it has been necessary to achieve a square matrix with the same number of columns representing "distinct fishing" and row representing "distinct species". In this regard it is a precondition that one fishing category correspond to one species group. As it appear fishing category 2 is characterized by targeting different species that correspond to several of the species group. However, it was found that fishing category 2 could be merged with fishing category 3 because both categories probably target flatfish in a practical sense[17].

[17] Even though fishing category has the highest standard catch value from codfish it is assumed that flatfish is the real target fish. The reason is that flatfish are caught with considerable smaller energy consumption in this fishing category. Hence, it must be assumed that behavior of the fishermen is more influenced by the goal of catching flatfish than codfish.

Then we have six fishing categories and seven species groups, of which one represents to target species (herring and mackerel) and two represents respectively mixed fish and other edible fish, which is quite imprecise. Therefore it has been necessary to make the following additional adjustments:

- Category 5 has been divided in two categories – one for only herring (5a) and one for only mackerel (5b).
- Category 7 have been divided in three categories – one for prawn (7a), one for shrimp (7b) and one for mussels (7c). Category 7 b and 7 c contains only shrimp and mussels, while category 7a contains considerable amounts of by catch.
- Finally the species category termed "other fish", have been distributed equally between codfish and flatfish.

The adjustments have been followed up by adjustments in fuel consumption.

Co-product allocation
On the basis of this it has been possible to establish the fuel consumption per kg target fish by means of system expansion.

There have been established a 9x9 matrix, which can be solved by means of linear algebra. I in other words it is possible to determine how much output we need from each fishery, in terms of mixed fish, to get a total output from all fishing categories of lets say 1 kg codfish, or 1 kg flatfish etc. With this knowledge combined with figures for the average fuel consumption in each fishing category, it has been possible to establish the fuel consumption for the 9 species groups. Further details are available in the CD – see app. 5 document C.

Results in terms of adjusted fishing categories

The results regarding fuel consumption for nine species / species groups are illustrated in table 3. For further details see the CD app. 5 document C.

__Table 3:__ Composition of catches in nine adjusted fishing categories.

	Demersal fish		Shell fish				Pelagic		Ind.
	1	2a	7a	7b	4	7c	5a	5b	6
Fishing category	Atl. cod	Eu. plaice	Prawn	Shrimp	Norway lobster	Mussels	Herring	Mackerel	Tobis etc.
Number of vessels (units)	370	419	346	26	182	67	23	23	96
Fuel per vessel (1000 l)	37	67	144	98	158	21	704	141	556
	Relative fuel consumption - per caught mixed fish (liter per kg)								
Relative fuel consump.	0,37	0,63	0,17	1,03	1,56	0,01	0,12	0,06	0,07
	Catch per vessel (percentage)								
Codfish	0,70	0,34	0,07	0,00	0,32	0,00	0,00	0,00	0,00
Flatfish	0,09	0,50	0,04	0,00	0,19	0,00	0,00	0,00	0,00
Prawn	0,00	0,00	0,01	0,00	0,08	0,00	0,00	0,00	0,00
Shrimp	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00
Norw. Lobster	0,00	0,00	0,00	0,00	0,19	0,00	0,00	0,00	0,00
Mussels	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
Herring	0,15	0,00	0,13	0,00	0,03	0,00	0,48	0,00	0,03
Mackerel	0,00	0,00	0,03	0,00	0,00	0,00	0,00	0,48	0,00
Industrial fish	0,06	0,16	0,72	0,00	0,17	0,00	0,52	0,52	0,97
All per vessel	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**

All catches amounts to 1.518.561 tons, which is close to the official statistic that says 1.534.000 ton (Fiskeridirektoratet, 2001b).

This table shows the results in terms of fuel consumption per kg mixed fish, where the all fuel has been equally distributed among the different species according the their weight. To establish a more accurate picture of the fuel consumption for different species, we need to apply system expansion[18]. The methodology is explained in chapter three, and the results are presented for each species in the following sections together with additional explanations.

Scope

Aspects related to time-, geographical- and technological scope is described separately for each for the nine species group in section 5.2 - 5.10.

[18] There are also other opportunities such as economical allocation. The results based on economical allocation shown in the last section of this appendix.

Representativenss and validation (general aspects)

As mentioned the total sample is 330 fishing firms, representing 1528 firms or 99% of the Danish fishery measured in value. The sample size in each production category (1 to 7) is described below:

1) Sample 96 fishing firms – total number of firms 438
2) Sample 58 fishing firms – total number of firms 370
3) Sample 45 fishing firms – total number of firms 244
4) Sample 30 fishing firms – total number of firms 175
5) Sample 39 fishing firms – total number of firms 182
6) Sample 14 fishing firms – total number of firms 23
7) Sample 46 fishing firms – total number of firms 96

Large vessels are over represented in two ways. First of all the 1528 vessels, which represents 99% of the total landing value are among the largest vessels. There are roughly 4000 vessels in Denmark. Secondly the samples within each production category are made in such a way that larger vessels are over represented as well. Each production category (1-7) is divided in 5 sub-categories depending on the total SCV. The sub-categories with the lowest SCV are represented with 11%. The other categories are represented with 15%, 21%, 29% and 40%, respectively. This is made because the larger represents a larger economical value of landings and because the statistical variation among the larger vessels are larger (Fødevareøkonomisk Institut, 2001b)

It is assessed that the data for energy consumption in the present dissertation have a high level of representativeness.

Validation
The major strengths of the result are that they represent the whole Danish fishing fleet, and that I got knowledge about the total aggregated fuel consumption in the whole fishing fleet. Thus, is has been possible to continuously verify the calculations – by mass balances.

Uncertainty about the aggregated consumption. However, the number for the total fuel consumption as well as fuel consumption for different segments is not necessarily 100 % correct. First of all some of the data are based on estimates of the amount of fuel consumption based on how much money a given vessel spend on fuel in a given period and the average fuel price in the same period. This may not reflect the precise amount consumed and there is also uncertainty related to how much fuel the vessel already had in the tanks in the start of the period.

It must be stressed that The Danish Statistical Institute has a considerable higher estimation for the total aggregated fuel consumption in the Danish fishing fleet. They state that the total energy consumption in the Danish fishery was 9.451 TJ in year 2000 (Danmarks Statistik, 2003). This is approximately 263 million liters of diesel oil, if it is assumed that the energy content in diesel is 36 MJ per liter. One reason behind the differences is probably that the national statistics are based on the consumption in the Danish harbors, where fuel is sold to both Danish and foreign vessels as well as some industries (Nielsen, 2003a).

Uncertainty about fuel distribution between species. As mentioned I have supplemented the original data with data for certain fisheries, such as herring, mackerel, shrimps and blue mussels. These data are based on a very limit number of vessels and may not represent an average.

The uncertainty margin is difficult to assess precisely. However, it is assumed that the uncertainty will generally not exceed 20%. The results for the different fish are further validated under each section dealing with the given species.

It is assessed that the data for energy consumption in the present dissertation have a high level of reliability.

A5.2 Cod fish fishery

Codfish[19] is a family of coldwater fish living in shallow as well as deep waters in the seas around Denmark (Muus and Nielsen, 1998). Atlantic cod constitutes nearly 90% of the total catch volume of codfish, and is the most important fish for the Danish Fishery in terms of value – see the CD (app. 5 document C).

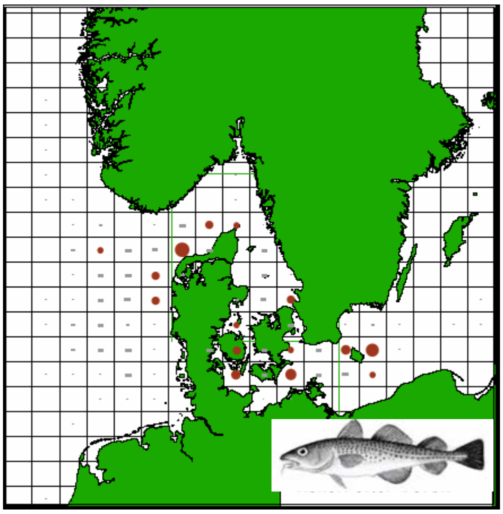


Figure 1. *Danish cod fishery in year 2000 (Petersen, 2001)*

Resource situation. Most codfish are embraced by quota. In recent years the of cod have decreased dramatically and the cod stocks are presently in a very critical situation (Petersen, 2001; Fiskeridirektoratet, 2001a).

Fishing grounds. The Danish fishery after cod is concentrated in the North Sea as well as in the Eastern and Western Baltic. Codfish are also caught in Kattegat and Skagerak, see figure 1 (Petersen, 2001).

Seasons and use. The fish is caught all year round, but the high season is the winter (January – Marts), where the quality is best. Codfish is used for human consumption and is typically sold to consumers as frozen or fresh filet (Fiskerdirektoratet, 2001a).

[19] Codfish generally include 15 different species: Atlantic cod, Haddock, Whiting, Pollack, Saithe, European hake, Ling, Blue ling, Tusk, Blue whiting, Norway pout, Poor cod, Roundnose grenadier and Fourbearded rockling. However, I have left out Blue whiting and Norway pout, because these two species typically are used as industrial fish and therefore also belongs to the group of industrial fish. (Fiskeridirektoratet, 2001a)

Process description

About 38% of all codfish are caught in regular codfish fishery by vessels in Fishing Category 1, with a moderate amount of by-catches of herring and flatfish. Most of the remaining cod is caught in flatfish fishery and prawn fishery (fishing Categories 2a and 7a – referring to the adjusted fishing categories. (Fødevareøkonomisk Institut, 2002b). See also the CD (app. 5 document C).

The average size of Danish vessels targeting Atlantic cod was 25 GT in 1999. The most common fishing gear applied in fisheries targeting Atlantic cod is bottom trawl (49%) but gill net is also applied frequently (29%). Other gears applied are pair trawl (10%) and Danish seine (10%) – see appendix 2.

Processes included

Following processes are included: Steaming to and from the fishing ground, catch phase and related energy requirements for cooling of ice[20], hauling equipment etc.

Construction and maintenance of the vessels are not included, although exchanges may be of some importance – see chapter 4 (Tyedmers, 2001).

Product flow and exchanges

Codfish are gutted on the Sea, and typically landed with head on. One kg of landed gutted cod, correspond to 1,18 kg caught cod (Fiskerdirektoratet, 2002b). After gutting, the fish are stored with ice until landing. The ice consumption is roughly 0.5-1,0 kg ice per kg fish. Guts are dropped in the Sea. (Ziegler, 2002; Andersen, 1998; Danish seine 1, 2001)

As figure 2 point out, the fishery is characterized by targeting codfish, but there will always be a certain amount of incidental catch consisting of undersized fish, non-target fish and benthos etc. Part of the incidental catches and sometimes also part of the target fish, may be discarded together with ben-

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[20] Nearly, all Danish fishing vessels have cooling systems onboard that keep the ice cold. Ice machines are used in other countries e.g. among the Dutch Beam trawlers. Ice machines are relatively space demanding, because it is necessary to bring fresh water from the harbor, or to have an additional de-salting machine onboard (Danish seine 1, 2001)

thos and guts. The output is landed gutted target fish, in this case codfish and a certain amount of valuable gutted by-catch (se figure 2)

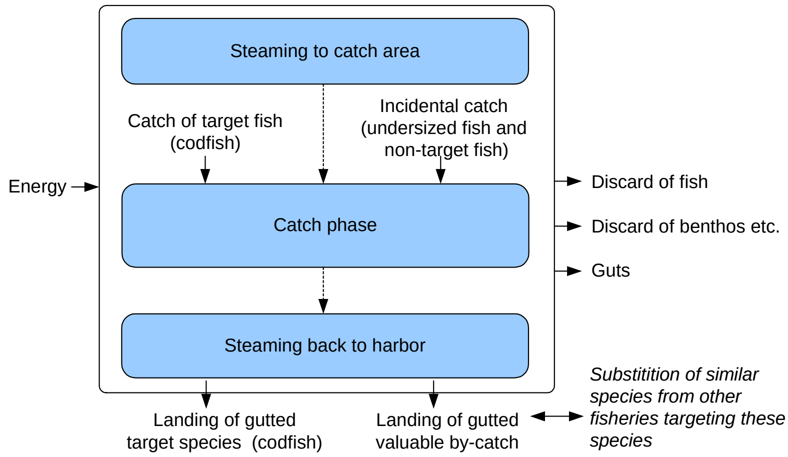

Figure 2. *Illustration of the product flow and the energy input in codfish fishery.*

The analysis in this appendix only deals with the energy consumption per kg target fish. However, discard of fish, benthos and guts will be reflected in the energy consumption because a large discard, means that the energy consumption will be distributed among fewer fish. Hence, a large discard will result in large energy consumption – other things being equal.

Data collection and treatment

Data for catches and fuel consumption are based on fishermen's records and obtained by interviews and databases, see app. 5.1.

Exchanges associated specifically with cod fishery have been determined from Fishing Category 1: Codfish fishery (see appendix 5.1 – fishing categories). By-catches in Codfish fishery have been eliminated by system expansion[21]. The table below shows the result of the system expansion, in terms of

[21] System expansion is used when more than one useful product is generated by a process. The alternative production process for each by-catch, which is affected by

the changes in total catch (C) from each fishing category (n) necessary to produce 1 kg of codfish. Further details are available on the CD (app. 5 document C).

Table 4. *Necessary outputs and fuel consumption for each fishing category necessary to provide one kg of caught flatfish*

Fishing category		**C_n (kg)**	**DC_n (l per kg)**	**$DC_{nCodfish}$ (liter)**
No.		Name		
1	Codfish fishery	1,55	0,37	0,58
2 and 3	Flatfish fishery	-0,26	0,63	-0,17
7a	Prawn fishery	0,07	0,17	0,01
7b	Shrimp fishery	0,00	1,03	0,00
4	Norway lobster fishery	-0,01	1,56	-0,02
7a	Mussels fishery	0,00	0,01	0,00
5a	Herring fishery	-0,51	0,12	-0,06
5b	Mackerel fishery	0,00	0,06	0,00
6	Indutrial fish fishery	0,16	0,07	0,01
	Liter of fuel per kg caught codfish ($DC_{Codfish}$)			**0,36**

The diesel consumption per kg of codfish, $DC_{Codfish} = \Sigma C_n \cdot DC_n$, where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught codfish, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
$DC_{nCodfish}$: The fuel consumption for fishing category n – necessary to provide the output C_n

the change in output from the codfish fishery, is included in the considered system in proportion to the way it is affected. Since subtracted fishing categories have by-catches as well, many fishing categories are involved in the system expansion and both negative and positive changes are observed.

Results

As illustrated the fuel consumption for codfish is estimated to **0,36 liter per kg caught codfish**. Since codfish is gutted on board and the residuals are dropped in the Sea, the diesel consumption determined per kg landed fish are 1,18 times higher, as one kg of landed fish is equivalent to roughly 1,18 kg caught cod (Fiskeridirektoratet, 2001a).

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels – see European Environment Agency (2001).

Scope

Time and geographical scope

The data cover activities related to Danish fishing vessels, operating in Danish waters (roughly within 200 Nautical miles from the coastal zone) and landing fish in Danish harbours. For further descriptions of fishing grounds and seasonal changes in the fishery – see the introduction to this section.

Fuel consumption per kg of catch in the Danish fishery, has increased slightly during the last two decades. This development is supposedly going to continue and exchanges associated with cod fishery are expected increase slowly. This is further described in chapter 4.

Technological scope

Fishing vessels equipped with diesel engines are used for all professional fishing in Denmark. The sizes of vessels as well as fishing gear vary depending on local conditions, traditions and target species (see appendix 2).

The average age of fishing vessels is more than 30 years, but the diesel engines applied are generally modern and well maintained (Fødevareministeriet, 2000). For emission data see European Environment Agency (2001).

Validation and representativeness

Validation
The average diesel consumption is in accordance with similar observations by Tyedmers (2001), who estimates that the average fuel consumption is 0,51 liter per kg landed demersal fish, using mass allocation. Tyedmers covers the period 1997 to 1999 and involves 29 fisheries from Canada, Norway, Iceland and Germany. Codfish was the most important fish in terms of volume in 2/3 of the fisheries, analyzed by Tyedmers.

It should be noticed that Tyedmers figures are per kg landed fish instead of per kg caught fish. Furthermore, Tyedmers have not based his study on measured data for fuel consumption, but a model that correlates effort (in terms of engine power and Sea days) with fuel consumption. Even though the model appears to give accurate results in average – there may be significant uncertainties considering a single fishery.

Based on the conversion factor for Atlantic cod, it can be established that 0,36 liter per kg “caught” codfish, based on “system expansion”, correspond to 0,44 liter per kg “landed” cod fish, based on “mass allocation”. This is relatively close to Tyedmers 0,51 liter per kg landed cod.

The fuel consumption is also in good agreement, with observations by Nielsen (2002b) – see chapter 4 and the CD (app. 5 document D). However, it is somewhat lower than previously observed in a Swedish study by Ziegler (2002). The higher diesel consumption observed by Ziegler (2002) can to some extend be explained by different geographical conditions and different accounting principles.

Representativity
More than 99% of Danish cod fishery has been included and the data provides an almost complete coverage of the Danish cod fishery. Thus, the data and the estimated fuel consumption, represents average Danish cod fishery in year 2000. Further details related to sample procedure etc. see appendix 5.1.

It should be noted that the fuel consumption can vary considerably between different fisheries depending on vessel size and fishing gear, as described in chapter 4.

A5.3 Flatfish fishery

Flatfish[22] is a family of fish living on sand- or clay seafloor down to about 200 meters in salty cold waters around Denmark (Muus and Nielsen, 1998).

European Plaice constituted approximately 65 percent of the total catches of flatfish in year 2000 and was the third most important species in terms of value in the Danish Fishery – see the excel file on the CD (app. 5 document C).

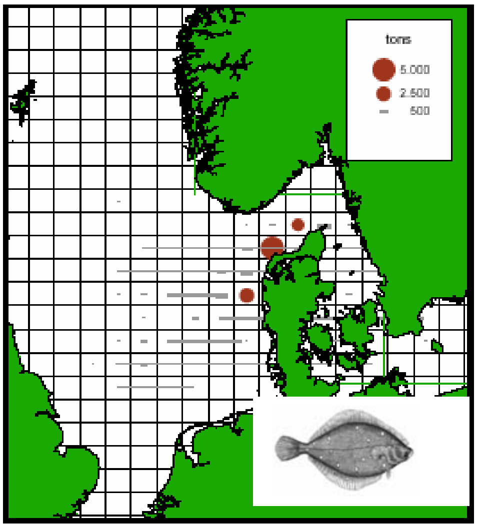

Figure 3. *Danish fishery after European plaice in 2001 (Petersen, 2002)*

Resource situation. Most flatfish are embraced by quota. The catches of plaice have been declining in recent years and ICES suggest that the fishery is reduced with 40%. However the resource situations is not critical as for cod (Petersen, 2002; Fiskeridirektoratet, 2001a)

Fishing grounds. Danish Plaice fishery is concentrated in the North Sea and so is most of the flatfish in general - see figure 3 (Petersen, 2002)

Seasons and use. European plaice is caught all year, but summer is the main season. Sole fishery, which is also important, has a high season in the spring. Flatfish is used for human consumption and is typically sold to consumers as frozen or fresh filet. A considerable part is also sold as panned or filled frozen filets, as described in chapter 2. (Fiskeridirektoratet, 2001a)

[22] Flatfish consist of 12 different species: European Plaice, European Flounder, Common dab, Witch founder, Lemon sole, Common sole, Turbot, Brill, Megrim, Atlantic halibut, Greenland halibut and American plaice (Fiskeridirektoratet, 2001a)

Process description

Vessels in fishing category 2a caught 55 percent of the flatfish. The rest were mainly caught in prawn fishery (category 7a).

The average size of Danish vessels catching Flatfish was 41 GT in 1999. The most common fishing gear applied in fishery targeting Flatfish is bottom trawl (42%), Danish seine (29%), beam trawl (15 %) and gillnet (12%) – see appendix 2.

Processes included
As for codfish – see app. 5.2.

Product flow
Flatfish are gutted on the Sea, but the head is not removed. Flatfish lose only little weight during this process – 1 kg landed flatfish corresponds to 1,05 kg caught flatfish (Fiskeridirektoratet, 2001a).

Other aspects related to product flow are similar to the situation for codfish – see app. 5.2.

Data collection and treatment

Data for catches and fuel consumption are based on fishermen's records and obtained by interviews and through databases, see app. 5.1.

Exchanges associated specifically with flatfish fishery have been determined from Fishing Category 2 and 3, which have been merged to category 2a – see app. 5.1 By-catches in Flatfish fishery have been eliminated by system expansion[23]. The table below shows the result of the system expansion, in terms of the changes in total catch (C) from each fishing category (n) neces-

[23] System expansion is used when more than one useful product is generated by a process. The alternative production process for each by-catch, which is affected by the change in output from the codfish fishery, is included in the considered system in proportion to the way it is affected. Since subtracted fishing categories have by-catches as well, many fishing categories are involved in the system expansion and both negative and positive changes are observed.

sary to produce 1 kg of Flatfish. Further details are available on the CD (app. 5 document C).

***Table 5.** Necessary outputs and fuel consumption for each fishing category necessary to provide one kg of caught flatfish.*

Fishing category		C_n (kg)	DC_n (l per kg)	$DC_{nFlatfish}$ (liter)
No.	Name			
1	Codfish fishery	-1,04	0,37	-0,39
2 and 3	Flatfish fishery	2,16	0,63	1,36
7a	Prawn fishery	0,04	0,17	0,01
7b	Shrimp fishery	0,00	1,03	0,00
4	Norway lobster fishery	-0,01	1,56	-0,01
7a	Mussels fishery	0,00	0,01	0,00
5a	Herring fishery	0,33	0,12	0,04
5b	Mackerel fishery	0,00	0,06	0,00
6	Indutrial fish fishery	-0,49	0,07	-0,03
	Liter of fuel per kg caught flatfish ($DC_{flatfish}$)			**0,97**

The diesel consumption per kg of flatfish, $DC_{flatfish} = \Sigma C_n \cdot DC_n$, where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught flatfish, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
$DC_{nFlatfish}$: The fuel consumption for fishing category n – necessary to provide the output C_n

Results

As illustrated the fuel consumption for flatfish is estimated to **0,97 liter per kg caught flatfish**. Since flatfish are gutted on board and the residuals are dropped in the Sea, the diesel consumption determined per kg landed fish is 1,05 times higher (Fiskeridirektoratet, 2001a)

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels. For emission data see European Environment Agency (2001).

Technical scope

The time-, geographical- and technological scope is the same as for codfish - see app. 5.2. See also introduction to this section.

Validation and representativeness

Validation

The average diesel consumption is in good agreement, with similar observations by Nielsen (2002b). However, it is somewhat lower than previously observed by Tyedmers (2001), who estimate that the fuel consumption is 2,3 liter per kg landed fish in German flatfish fisheries, targeting plaice.

If we take an average of the fuel consumption in all fisheries in Tyedmers study, where flatfish is the most or second most important species in terms of volume, the average fuel consumption is 1,74 liter per kg landed fish, which is somewhat closer to the figure calculated in this dissertation.

The higher diesel consumption observed in the German fisheries can be explained by the fishing gear applied, which is typically bottom trawl and beam trawl. The Danish fishery covers a wider range of active and passive fishing gears, including Danish seine, which have very low fuel consumption per kg caught flatfish – see chapter 4.

Representativeness

As for codfish – see section 5.2.

A5.4 Norway lobster fishery

The Norway lobster is a large shellfish living in caves at the bottom of the Sea at depths ranging from 30 to 500 meters (Petersen, 2002).

Resource situation. In recent years the fishery after Norway lobster has increased significantly because of the reduced quotas on cod. The stock is difficult to estimate but it is generally assumed that the fishery is sustainable. The fishery is embraced by so called precautionary quota. However it is assumed that the quota have only minor restrictive consequences for the fishery (Petersen, 2001; Fiskeridirektoratet, 2001a)

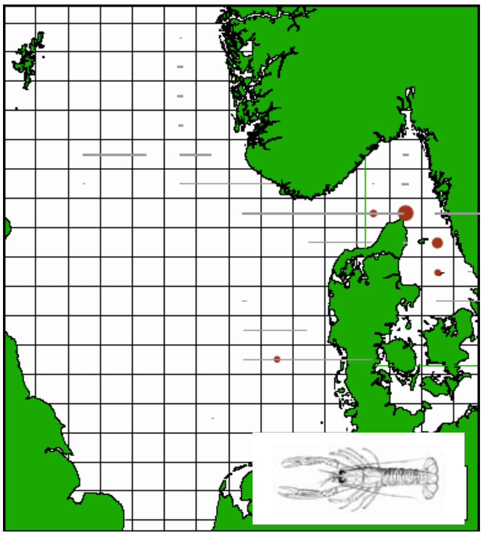

Figure 4. *Danish Norway lobster fishery in year 2000 (Petersen, 2001)*

Fishing grounds. The Danish fishery targeting Norway lobster is situated in the North Sea, Skagerak and Kattegat. A considerable part of the fishery takes place near Skagen (Northern Jutland), where most lobsters are landed – see fig 4 (Petersen, 2001).

Seasons and use. Norway lobsters are caught all the year but the landings are smaller during wintertime. It is used for human consumption and is typically sold frozen or fresh to consumers. (Fiskeridirektoratet, 2001a).

Proces description

71% of Norway lobsters are caught in regular Lobster fishery (Fishing Category 4) with considerable by-catches of cod- and flatfish. The remaining

Norway lobsters are mainly caught in prawn fishery, fishing Category 7a (Fødevareøkonomisk Institut, 2002b).

The average size of Danish vessels catching Norway lobster was 69 GT in 1999. The most common fishing gear applied in fishery targeting Norway lobster is bottom trawl (97%). (Fiskeridirektoratet, 2001b).

Processes included
See section 5.2 cod fishery

Product flow
Norway lobsters are landed alive or as tails after removing the rest of the body. Cut-offs from the lobsters are dropped in the Sea. The difference in weight between lobster tails and whole lobsters is typically a factor 3,3 (Fiskeridirektoratet, 2001a). The Norway lobsters are stored with ice (about 0.5 – 1,0 kg ice per kg) or frozen until landing (Ziegler, 2002, Andersen, 1998, Danish seine 1, 2001).

Other aspects related to product flow are similar to the situation for codfish – see app. 5.2.

Data collection and treatment

Data on catches and fuel consumption are based on fishermen's records and obtained by interviews and through databases, see section 5.1.

Exchanges associated specifically with Norway lobster fishery have been determined from fishing category 4 "Norway lobster". By-catches have been eliminated by system expansion[24]. The table below shows the result of the system expansion, in terms of the changes in total catch (C) from each fishing category (n) necessary to produce 1 kg of Norway lobster. For further details see excel file on the CD (app. 5 document C).

[24] System expansion is used when more than one useful product is generated by a process. The alternative production process for each by-catch, which is affected by the change in output from the codfish fishery, is included in the considered system in proportion to the way it is affected. Since subtracted fishing categories have by-catches as well, many fishing categories are involved in the system expansion and both negative and positive changes are observed.

Table 6. *Necessary outputs and fuel consumption for each fishing category necessary to provide one kg of Norway lobster*

Fishing category		**C_n (kg)**	**DC_n (l per kg)**	**$DC_{nLobster}$ (liter)**
No.	Name			
1	Codfish fishery	0,48	0,37	0,18
2 and 3	Flatfish fishery	0,45	0,63	0,29
7a	Prawn fishery	-37,62	0,17	-6,33
7b	Shrimp fishery	-0,01	1,03	-0,01
4	Norway lobster fishery	6,02	1,56	9,41
7a	Mussels fishery	0,00	0,01	0,00
5a	Herring fishery	8,69	0,12	1,03
5b	Mackerel fishery	2,05	0,06	0,12
6	Industrial fish fishery	20,93	0,07	1,36
	Liter of fuel per kg caught Norway lobster ($DC_{Lobster}$)			**6,05**

The diesel consumption per kg of Norway lobster, $DC_{Lobster} = \Sigma C_n \cdot DC_n$, where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught Norway lobster, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
$DC_{nLobster}$: The fuel consumption for fishing category n – necessary to provide the output C_n

Results

As explained the fuel consumption is estimated to **6,05 liter per kg caught Norway lobster**. Since Norway lobster is gutted on board and the residuals are dropped in the Sea, the diesel consumption determined per kg landed lobster tail are 3,33 times higher, because one kg of landed lobster tail is equivalent to roughly 3,33 kg caught whole Norway lobster (Fiskeridirektoratet, 2001a).

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels. For emission data see European Environment Agency (2001).

Technical scope

The time-, geographical- and technological scope is the same as for codfish - see app. 5.2. See also introduction to this section.

Validation and representativeness

Validation

The observed average diesel consumption is in good agreement, with similar observations of selected vessels targeting Norway lobster in the Danish Fishery (Nielsen, 2002b). However, it is considerably higher than estimated by Tyedmers (2001). Tyedmers has made a study of Icelandic vessels, where the diesel consumption is 1 liter per kg landed Norway lobster, using mass allocation. Norway lobster constituted 27% of the landing volume.

Some of the difference can be explained by differences in allocation procedure. If we consider Danish fishery targeting Norway lobster, where 19% of the catch volume is Norway lobster, the fuel consumption can be calculated to 1,56 liter per kg using mass allocation. This shows how important the allocation procedure is. The rest of the difference can be explained by the fact that Tyedmers figures are per landed fish instead of per kg caught fish as well as differences in fishing ground, fishing methods etc.

Representativeness

As for codfish – see section 5.2.

A5.5 Northern Prawn fishery

Prawn fishery covers fishery after northern prawn. Northern Prawn is living on soft bottom of deep waters (50-900 meters) in the North Sea (Muus and Nielsen, 1998).

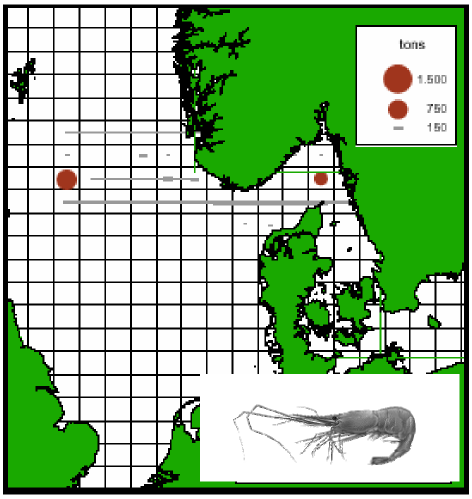

Figure 5. *Danish fishery after Northern Prawn (Petersen, 2002)*

Resource situation. Northern prawn fishery is restricted through quota, but it is assumed that the fishery is sustainable considering the resource situation (Petersen, 2002).

Fishing grounds. The Danish fishery after Northern Prawn is mainly localized in North Sea, between Norway and Scotland as well as in Skagerak, see figure: Danish Northern prawn fishery in 2001 (Petersen, 2002).

Seasons and use. The landings of northern prawn, takes place at all times of the year, but with a high season during summer. Prawns are used for human consumption and are typically sold to consumers as frozen or fresh (Fødevareøkonomisk Institut, 2002b; Fiskeridirektoratet, 2001b).

Process description

71 percent of the prawns are caught by vessels in Fishing Category 7a prawn fishery, with considerable by-catches of industrial fish, codfish and flatfish. This fishery is also responsible for the catch of 27% of all Norway lobsters. The rest of the prawns are mainly caught in Norway Lobster fishery, Fishing Category 4 (Fødevareøkonomisk Institut, 2002b).

The average size of Danish vessels targeting prawn and shrimp was 147 GT in 1999 (I had no access to data concerning only prawn). A sample analysis of 9 vessels targeting prawn and 6 vessels targeting shrimp, show that the vessel size is very different. The average tonnage in the first group was 177 GT, while the average for shrimp vessels were 27 GT (Nielsen, 2002b).

The most common fishing gear applied in fishery targeting prawn and shrimps were trawl (about 41%) and beam trawl (about 19%) in 1999. The rest has been registered as unspecified fishing gear – see appendix 2.

Processes included
See section 5.2 codfish fishery.

Product flow
Prawns are not further processed on the Sea. After being caught, the prawn are stored with ice (0.5-1,0 kg ice per kg) or frozen until landing (Ziegler, 2002; Andersen, 1998; Danish seine 1, 2001).

Other aspects related to product flow are similar to the situation for codfish – see app. 5.2.

Data collection and treatment

Data on catches and fuel are based on fishermen's records and obtained by interviews and through databases, see section 5.1.

Exchanges associated specifically with prawn fishery have been determined from fishing category 7 "Shellfish and mollusks" modified to 7a "Prawn". By-catches have been eliminated by system expansion[25]. The table below shows the result of the system expansion, in terms of the changes in total catch (C) from each fishing category (n) necessary to produce 1 kg of Prawns. Further details are available on the CD (app. 5 document C).

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[25] System expansion is used when more than one useful product is generated by a process. The alternative production process for each by-catch, which is affected by the change in output from the codfish fishery, is included in the considered system in proportion to the way it is affected. Since subtracted fishing categories have by-catches as well, many fishing categories are involved in the system expansion and both negative and positive changes are observed.

Table 7. *Necessary outputs and fuel consumption for each fishing category necessary to provide one kg of Northern prawn*

Fishing category		C_n (kg)	DC_n (l per kg)	DC_{nPrawn} (liter)
No.	**Fishing category**			
1	Codfish fishery	-4,68	0,37	-1,76
2 and 3	Flatfish fishery	-4,97	0,63	-3,13
7a	Prawn fishery	86,23	0,17	14,50
7b	Shrimp fishery	0,01	1,03	0,01
4	Norway lobster fishery	-1,95	1,56	-3,05
7a	Mussels fishery	0,00	0,01	0,00
5a	Herring fishery	-19,55	0,12	-2,32
5b	Mackerel fishery	-4,70	0,06	-0,28
6	Indutrial fish fishery	-49,39	0,07	-3,22
	Liter of fuel per kg caught prawn (DC_{Prawn})			**0,76**

The diesel consumption per kg of prawn and shrimp, $DC_{Prawn} = \Sigma C_n \cdot DC_n$, where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught Northern prawn, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
DC_{nPrawn}: The fuel consumption for fishing category n – necessary to provide the output C_n

Results

As illustrated the fuel consumption is estimated to **0,76 liter per kg caught prawn**. Since prawn is not gutted on board the fuel consumption mentioned above, is equal to the fuel consumption per landed prawn.

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels. For emission data see European Environment Agency (2001).

Technical scope

The time-, geographical- and technological scope is the same as for codfish - see app. 5.2. See also introduction to this section.

Validation and representativeness

Validation

Tyedmers (2001) estimated that the energy consumption is 0.92 liter per kg landed shrimp/prawn in 12 fisheries targeting shrimp and prawn, with a small by-catch of other fish. Tyedmers results do not tell anything about the proportion between shrimps and prawn, and it is therefore difficult to compare.

Observations by Nielsen (2002b), which cover 9 vessels targeting prawn, shows that the fuel consumption is 1,53 liter pr kg prawn based on mass allocation, and 1,62 liter per kg prawn based on system expansion. This is somewhat higher than observed in the study of the whole Danish fishing fleet (0,76 l per kg). The reason why Nielsen's figures are higher is that the 9 vessels in the sample have a very small amount of by-catch, while the vessels in the prawn category, covering the whole Danish fishing fleet, have a high amount of by-catch such as Norway lobster. Norway lobster is typically very energy demanding to catch and therefore reduces the fuel consumption allocated to prawn.

Thus it appear that prawn actually are more energy demanding than shrimps, when comparing vessels in the sample analysis, while the opposite is the case when considering the whole fishery. Which figure is the best depends on the purpose of the study.

Representativeness

As for codfish – see section 5.2

A5.6 Shrimp fishery

Common shrimps lives on the bottom of shallow waters such as the inner Danish waters.

Resource situation. It has not been possible to find viable information concerning the resource situation for shrimp fishery.

Fishing grounds. The Danish fishery after common shrimp mainly takes place in the inner Danish waters (Muus and Nielsen, 1998).

Seasons and use. The landings of common shrimp are low during winter. Shrimps are used for human consumption and are typically sold to consumers as frozen or fresh (Fiskeridirektoratet, 2001b).

Process description

Vessels in Fishing Category 7b, shrimp fishery, catch approximately 95% percent of all the shrimp. The remaining are mainly caught in Norway Lobster fishery, Fishing Category 4 (Fødevareøkonomisk Institut, 2002b).

The average size of vessels in mussel fishery is 27 GT. The most common fishing gear applied in shrimp and prawn fishery is trawl – see appendix 2. Shrimps are not further processed on the Sea.

Processes included
See section 5.2 codfish fishery.

Product flow
After being caught, the shrimp are stored with ice (0.5-1,0 kg ice per kg) or frozen until landing (Ziegler, 2002; Andersen, 1998; Danish seine 1, 2001).

Other aspects related to product flow are similar to the situation for codfish, except from the fact the amount of by-catch is insignificant – see app. 5.2.

Data collection and treatment

Data on catches and fuel consumption are based on fishermen's records. All statistical information has been gathered and processed by The Danish Research Institute for Food Economics (Nielsen, 2002b).

The data cover 6 concerns with a yearly catch of 94.693 kg shrimp and a fuel consumption of 97.851 liter. As the fishery is a clean fishery without by-catches it can be calculated that the average fuel consumption 1,03 liter per kg caught shrimp, based on mass allocation (Nielsen, 2002b).

Exchanges associated specifically with shrimp fishery have been determined from fishing category 7 "Shellfish and mollusks" modified to 7b "Shrimp". The table below shows contributions to Shrimp fishery from all considered fishing categories after system expansion.

Table 8. *Necessary outputs and fuel consumption for each fishing category necessary to provide one kg of Shrimp*

Fishing category		C_n (kg)	DC_n (l per kg)	$DC_{nShrimp}$ (l per kg)
No.	**Fishing category**			
1	Codfish fishery	0,00	0,37	0,00
2 and 3	Flatfish fishery	0,00	0,63	0,00
7a	Prawn fishery	0,00	0,17	0,00
7b	Shrimp fishery	1,00	1,03	1,03
4	Norway lobster fishery	0,00	1,56	0,00
7a	Mussels fishery	0,00	0,01	0,00
5a	Herring fishery	0,00	0,12	0,00
5b	Mackerel fishery	0,00	0,06	0,00
6	Indutrial fish fishery	0,00	0,07	0,00
	Liter of fuel per kg caught shrimp (DC_{Shrimp})			**1,03**

The diesel consumption per kg of shrimp, $DC_{Shrimp} = \Sigma C_n \cdot DC_n$, where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught Shrimp, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
$DC_{nShrimp}$: The fuel consumption for fishing category n – necessary to provide the output C_n

Results

As mentioned in previous section the fuel consumption is estimated to **1,03 liter per kg caught shrimp**. Since shrimp is not gutted on board the fuel consumption mentioned above, is equal to the fuel consumption per landed shrimp.

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels. For emission data see European Environment Agency (2001).

Technical scope

The time-, geographical- and technological scope is the same as for codfish - see app. 5.2. See also introduction to this section.

Validation and representativeness

Validation

Tyedmers (2001) have investigates five clean shrimp fisheries from Norway, with a by-catch of other fish less than 20%. The fuel consumption is 0,91 liter per kg shrimp, based on mass allocation. This is on good accordance with my results of 1,03 liter per kg.

Representativeness

About 25% of Danish shrimp fishery has been included. The data and the estimated fuel consumption, represents average Danish clean shrimp fishery in year 2000 – see appendix 5.1. The fuel consumption may vary considerably between different fisheries depending on vessel size and fishing gear – see chapter 4.

A5.7 Blue Mussel fishery

Blue mussels are small shellfish living in coastal zone shallow waters at depths down to 10 meter. The mussels live at the Sea floor attached to stones, plants or stakes (Muus and Nielsen, 1998). More than 90% of Danish catches of mussel consist of blue mussels – see the excel file on the CD (app. 5 document C).

Figure 6. *Picture of a blue mussel, which is mainly caught in Limfjorden (Petersen, 2002)*

Resource situation. The fishery after blue mussels is strictly regulated and in 1999 there were 63 fishing vessels with a licens to operate in this fishery. The resource situation is not critical. (Petersen, 2002)

Fishing grounds. Three thirds of the blue mussels are caught in Limfjorden in Northern Jutland. The remaining is mainly caught in Kattegat (Petersen, 2002).

Seasons and use. Blue mussels are caught all the year, but the main seasons are spring and autumn. Blue mussels are used for human consumption, and are typically sold to the consumers as frozen (without shells). However mussels are also sold as tinned and canned and as fresh living mussels (Fiskeridirektoratet, 2001b).

Process description

The present data considers Danish blue mussels caught in "clean" blue mussel fisheries operating in Limfjorden in Northern Jutland in the calender year 2000. The average size of vessels in mussel fishery is 14 GT and the most common fishing gear applied is mussel dredge (96%) – see appendix 2.

Processes included

See app. 5.2 codfish

Product flow
Mussels are not handled on the Sea. The mussels are stored without cooling until landing (Andersen et al. 2000).

Other aspects related to product flow are similar to the situation for codfish, except from the fact the amount of by-catch is insignificant – see app. 5.2.

Data collection and treatment

Data on catches and fuel consumption are based on fishermen's records. All statistical information has been gathered and processed by The Danish Research Institute for Food Economics (Nielsen, 2002b).

Data collection covered 6 concerns with an average yearly catch of 1,649,836 kg blue mussels and a yearly diesel consumption of 20,525 liter. Hence, the average fuel consumption estimated to 0.012-liter per kg caught blue mussel.

Exchanges associated specifically with mussel fishery have been determined from fishing category 7 "Shellfish and mollusks" modified to "Mussel fishery". The table below shows contributions to Mussel fishery from all considered fishing categories after system expansion.

Table 9. N*ecessary outputs and fuel consumption for each fishing category necessary to provide one kg of mussels*

Fishing category		**C_n (kg)**	**DC_n (l per kg)**	**$DC_{nMusseld}$ (l per kg)**
No.	Name			
1	Codfish fishery	0,00	0,37	0,00
2 and 3	Flatfish fishery	0,00	0,63	0,00
7a	Prawn fishery	0,00	0,17	0,00
7b	Shrimp fishery	0,00	1,03	0,00
4	Norway lobster fishery	0,00	1,56	0,00
7a	Mussels fishery	1,00	0,01	0,01
5a	Herring fishery	0,00	0,12	0,00
5b	Mackerel fishery	0,00	0,06	0,00
6	Indutrial fish fishery	0,00	0,07	0,00
	Liter of fuel per kg caught mussel (DC_{Mussel})			**0,01**

The diesel consumption per kg of mussels, $DC_{Mussel} = \Sigma C_n \cdot DC_{n,}$ where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught Mussel, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
$DC_{nMussel}$: The fuel consumption for fishing category n – necessary to provide the output C_n

Results

As mentioned in previous section the fuel consumption is estimated to **0,012 liter per kg caught mussel**. Since mussels are not gutted on board the fuel consumption mentioned above, is equal to the fuel consumption per landed mussel. However, it should be noticed that the amount of waste in the form of sand and shells make a great deal of the total landings.

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels. For emission data see European Environment Agency (2001).

Scope

The time-, geographical- and technological scope is the same as for codfish - see app. 5.2. See also introduction to this section.

Concerning the time scope it should be stressed that the tendency of increasing fuel consumption is confirmed, by a time series of fuel consumption data from one vessel. The fisherman had experienced an increase in fuel consumption at 12,5% from 1995 to 1999 (Mussel fishery 1, 2001).

Validation and representativeness

Validation

The data gathered by the Danish Institute of Food Economics have been supplemented with telephone interview with 2 mussel fishermen, operating in Limfjorden in Northern Jutland.

The first had a tonnage of 15 GT, a fuel consumption at 27.000 liter and a catch of 2500 kg in 1999 (Mussel fishery 1, 2001). The second had a tonnage of 8 GT, a fuel consumption at 27.738 liter and a catch of 2455 ton mussels the same year (Mussel fishery 2, 2001). This is an average of 0,011 liter per kg, which is very close my results of 0,012 liter per kg caught blue mussels previously estimated.

Representativeness

About 10% of Danish mussel fishery has been included. The studied vessels are all under 20 GT and the average is 7 GT. This is somewhat smaller than the average size of mussel vessels. However, this is not assumed to have any significant influence on the results.

A5.8 Herring fishery

Herring is a small pelagic fish that migrates over large distances in shoals in the Northeast Atlantic area at depths down to 200 meter in the North Sea (Muus and Nielsen, 1998).

Resource situation. Herring fishery is restricted through quota, but the resource situations is not critical (Petersen, 2001)

Fishing grounds. The Danish fishery after herring covers several stocks and is centered in the North Sea, but significant catches are made in the Norwegian Sea, Skagerak and Kattegat as well as in Eastern and Western Baltics (Petersen 2001)

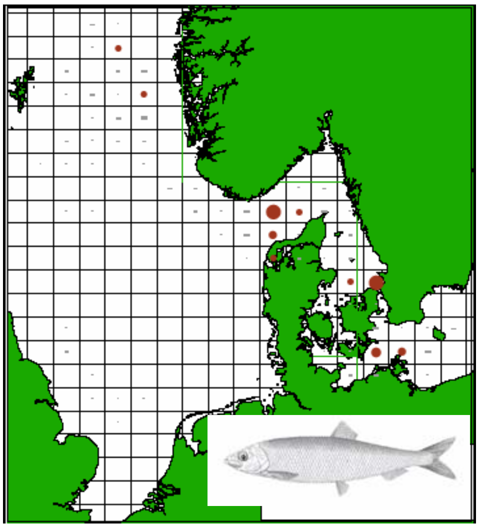

Figure 7. *Danish fishery after herring in year 2000 (Petersen, 2001)*

Seasons and use. Herring can be caught all the year but most fisheries takes place in the early summer and in the autumn. The type of herring varies depending on the season. The fat herrings called Matjes are caught during the early summer months. Herring is primarily used for human consumption and processed to pickled, canned, smoked, dried/salted-, fresh- or frozen herring. However a considerable part of the herring landings are used to produce fishmeal and oil (Fiskeridirektoratet, 2001a).

Process description

About 50% of all herrings are caught in regular herring fishery (Fishing Category 5a) with considerable by-catches of industrial fish. The remaining 50 % are primarily caught in Fishing Category 7a (prawn fishery), and as by-catch in category 6, industrial fish (Fødevareøkonomisk Institut, 2001b and 2002).

The average size of Danish vessels catching herring was 390 GT in 1999. The most common fishing gear applied in fishery targeting herring is pair trawl (50%), purse seine (40%) and trawl (10%). The trawl applied is termed pelagic trawl, which does not touch the Sea floor – see appendix 2.

Processes included
See app. 5.2 codfish.

Product flow
Herring is not gutted on the Sea, but typically stored in Refrigerated Sea Water (RSV) tanks, which cause emissions of blood water. The energy for cooling of the seawater, comes from the ship engines and is a part of the overall energy consumption (Purse seine, 2001).

Other aspects related to product flow are similar to the situation for codfish – see app. 5.2.

Data collection and treatment

Data for the total catches and fuel consumption for herring and mackerel (as one group) are based on fishermen's records, where the information has been gathered and processed by The Danish Research Institute for Food Economics (Nielsen, 2002b).

I have subdivided the fishing category 5 (herring and mackerel) in two distinct fishing categories 5a (herring) and 5b (mackerel). In this respect it has been necessary to gather additional catch and fuel data, which has involved 3 purse seine vessels and 5 trawlers targeting herring and mackerel in different periods of the year. The trawlers were situated in Esbjerg and fished in the North Sea and Skagerak (Pelagic trawl, 2001). The purse seine vessels fished in the North Sea, Skagerak and the Norwegian Sea (international zone). For the purse seiners, herring fishery took mainly place in the Norwegian Sea (Purse Seine, 2001).

For the purse seiners, I have not been allowed to provide information about total catches and fuel consumption. However, I got data for the relative fuel consumption in periods with only herring fishery, which mainly took plaice in the Norwegian Sea. The consumption for herring was calculated to 0,14 - 0,18 liter per kg caught herring, with an average of 0,16 liter per kg. This covered a total period of approximately three months of fishery in year 2000.

For the trawlers the total catch of herring in periods with only herring fishery was 7.848.445 kg in year 2000. The fuel consumption in the same period was 1.171.953 liter, which gives a average of 0,15 liter per kg herring. The fishery took place in the period January, February, half of Marts and half of august in the North Sea and Skagerak.

The catch of herring from the five trawl vessels is around 6% of the total herring fishery in Danmark. It must be assumed that the five trawlers and the three purse seine vessels together, represents around 10% of the Danish herring fishery.

Exchanges associated specifically with Herring fishery have been determined from Fishing Category 5a "Herring". By-catches have been eliminated by system expansion[26]. The table below shows the result of the system expansion, in terms of the changes in total catch (C) from each fishing category (n) necessary to catch 1 kg of herring. Further details are available on the CD (app. 5 document C).

[26] System expansion is used when more than one useful product is generated by a process. The alternative production process for each by-catch, which is affected by the change in output from the codfish fishery, is included in the considered system in proportion to the way it is affected. Since subtracted fishing categories have by-catches as well, many fishing categories are involved in the system expansion and both negative and positive changes are observed.

Table 10. ***N****ecessary outputs and fuel consumption for each fishing category necessary to provide one kg of herring*

Fishing category		**C_n (kg)**	**DC_n (l per kg)**	**$DC_{nHerring}$ (liter)**
No.	Name			
1	Codfish fishery	-0,01	0,37	0,00
2 and 3	Flatfish fishery	0,00	0,63	0,00
7a	Prawn fishery	0,02	0,17	0,00
7b	Shrimp fishery	0,00	1,03	0,00
4	Norway lobster fishery	0,00	1,56	0,00
7a	Mussels fishery	0,00	0,01	0,00
5a	Herring fishery	2,15	0,12	0,26
5b	Mackerel fishery	0,00	0,06	0,00
6	Industrial fish fishery	-1,17	0,07	-0,08
	Liter of fuel per kg caught/landed herring ($DC_{Herring}$)			**0,18**

The diesel consumption per kg of herring is, $DC_{Herring} = \Sigma C_n \cdot DC_{n,}$ where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught Herring, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
$DC_{nHerring}$: The fuel consumption for fishing category n – necessary to provide the output C_n

Results

As mentioned in previous section the fuel consumption is estimated to **0,18 liter per kg caught herring**. Since herring not gutted on board, the diesel consumption per kg landed herring is approximately equal to the fuel consumption per kg caught herring.

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels. For emission data see European Environment Agency (2001).

Technical scope

See app. 5.2 codfish.

Validation and representativeness

Validation

The average diesel consumption calculated in the present study (0.18 liter per kg herring) is close to previous estimates by Tyedmers (2001), who reported a diesel consumption of 0.16 liter herring fishery involving 66 vessels and 0,13 liter in a fishery involving 42 vessels – both Norwegian mobile seine fisheries.

The small difference between the Norwegian fisheries and the Danish can be explained by differences in allocation procedure/method, species composition catch area and specific fishing methods. Furthermore, Tyedmers have not measured the direct fuel consumption but instead estimated on the basis of Sea days and engine power, as earlier explained.

It should be noted that the relatively high fuel consumption observed in the present study can be explained by long steaming distances to relatively remote fishing grounds, such as the Norwegian Sea. This was common praxis for the vessels that were interviewed, but the situation may be different for other vessels. Therefore this figure is presumably a little too high.

As mentioned in appendix 5.1, the figures are based on interviews concerning the difference in fuel consumption between herring and mackerel fishery. The difference for five pair trawlers working in a pool fishery were found to be 1,5 in average - while it was found to be 2,66 for three purse seiners fishing herring in the Norway Sea and mackerel in the North Sea and Skagerak, thus an average of around a factor 2 was the estimation. This is clearly an assumption, and I have therefore chosen to calculate on the basis of two extremes, namely a factor 1,5 and a factor 2,66 respectively.

Using the factor 1,5 scenario the fuel consumption for herring is reduced from 0,18 to 0,17 liter per kg, while mackerel increases from 0,06 to 0,09 liter per kg. Using the 2,66 scenario the fuel consumption for herring is increased from 0,18 to 0,19 liter per kg, while mackerel is reduced from 0,06 to 0,03 liter per kg. Hence, it is assessed that the results are quite robust.

Representativeness

More than 99% of Danish Herring and mackerel fishery has been included and the data provides an almost complete coverage of the Danish pelagic fishery – see appendix 5.1. However, the category herring and mackerel have been subdivided. Therefore fuel consumption specifically associated with herring fishery has been estimated on the basis of interviews with 5 pelagic trawlers and 3 purse seiners. Thus, the coverage in terms of fuel consumption for herring fishery is only 10%, as mentioned earlier.

The fuel consumption may vary considerably between different fisheries depending on vessel size and fishing gear – see chapter 4. The data can be used as a rough estimate for fisheries in other countries, with a similar structure of the fishing fleet.

A5.9 Mackerel fishery

Mackerel is a small pelagic fish that migrates over long distances in shoals (Muus and Nielsen, 1998).

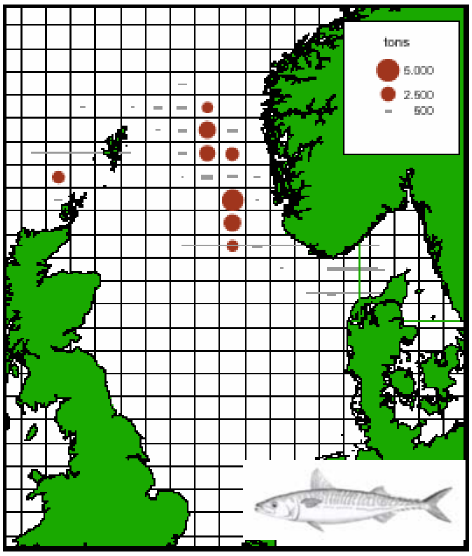

Figure 8. *Danish mackerel fishery in year 2001 (Petersen, 2002)*

Resource situation. The mackerel stocks in the North east Atlantic have been within safe biological limits the last 20 years (Petersen, 2002). However, the fishery is still embrace by quota (Fiskeridirektoratet, 2001a)

Fishing grounds. Most of the fishery takes place in the in the Northeast Atlantic where the mackerel can be found at depths down to 200 meter. Small amounts are also caught west of Scotland, close to the Faroe Islands and in Skagerak, see Figure 8 (Petersen, 2002).

Season and use. Mackerel fishery takes place in the autumn (August to November), but small amounts are also caught during winter (January). Virtually no fishery takes place during the spring and summer (Fiskeridirektoratet, 2001a). Mackerel is usually used for human consumption fresh or processed into canned smoked-, dried/salted- - or frozen products (Fiskeridirektoratet, 2001a).

Process description

As mentioned under herring fishery, I have subdivided the fishing category 2 (herring and mackerel) in two distinct fishing categories 5a (herring) and 5b (mackerel). In this respect I have gathered catch and fuel data for 3 purse seine and 5 trawlers targeting herring and mackerel in different periods of the year. The trawlers were situated in Esbjerg and fished in the North Sea and Skagerak (Pelagic trawl, 2001). The purse seiners fish in the North Sea, Skagerak and the Norwegian Sea (international zone). For the purse seiners, mackerel fishery took only place in the North Sea and Skagerak. (Purse Seine, 2001).

About two thirds of mackerel are caught in regular mackerel fishery Fishing Category 5b (75 %), with considerable amounts of by-catches of industrial fish. The remaining mackerels are mainly caught in prawn fishery, fishing Category 7a (Fødevareøkonomisk Institut, 2002).

The average size of Danish vessels targeting mackerel was 568 GT in 1999. The most common fishing gear applied in fishery targeting herring is purse seine (55%), pair trawl (35%) and trawl (10%). The trawl applied is termed pelagic trawl, which does not touch the Sea floor – see appendix 2

Processes included

See app. 5.2 codfish

Product flow

Mackerel is not gutted on the Sea, but typically stored in Refrigerated Sea Water (RSV) tanks, which cause emissions of blood water. The energy for cooling of the seawater, comes from the ship engines and is a part of the overall energy consumption.(Purse seine, 2001)

Other aspects related to product flow are similar to the situation for codfish – see app. 5.2.

Data collection and treatment

Data for the total catches and fuel consumption for herring and mackerel (as one group) are based on fishermen’s records, where the data have been provided by The Danish Research Institute for Food Economics (Nielsen, 2002b). As mentioned, data for specific mackerel fishery has been gathered through interviews with the owners of three purse seiners and the manager of five pair trawlers (Purse seine, 2001; Pelagic trawl, 2001).

For the purse seiners, I have not been allowed to provide information about total catches and fuel consumption. However I got data for the relative fuel consumption in periods with only mackerel fishery, which took plaice in the North Sea and Kattegat. The consumption for mackerel was calculated to

0,06 liter per kg caught mackerel. This covered a period of approximately three months fishery.

For the trawlers the total catch of mackerel in periods (October - 2000) with only mackerel fishery was 4.376.770 kg. The fuel consumption in the same periods was 434.936 liter, which is an average of 0,10 liter per kg mackerel. This represents around 12% of the total mackerel fishery in Denmark. It must be assumed that the five trawlers and the three purse seiners together, represents at least 15% of the Danish mackerel fishery.

Exchanges associated specifically with mackerel fishery have been determined from fishing category 5b "Mackerel". By-catches have been eliminated by system expansion[27]. The table below shows the result of the system expansion, in terms of the changes in total catch (C) from each fishing category (n) necessary to catch 1 kg of mackerel. Further details are available on the CD (app. 5 document C).

Table 11. ***N****ecessary outputs and fuel consumption for each fishing category necessary to provide one kg of mackerel.*

Fishing category		C_n (kg)	DC_n (l per kg)	$DC_{nMackerel}$ (liter)
No.	Name			
1	Codfish fishery	-0,01	0,37	0,00
2 and 3	Flatfish fishery	0,00	0,63	0,00
7a	Prawn fishery	0,02	0,17	0,00
7b	Shrimp fishery	0,00	1,03	0,00
4	Norway lobster fishery	0,00	1,56	0,00
7a	Mussels fishery	0,00	0,01	0,00
5a	Herring fishery	0,07	0,12	0,01
5b	Mackerel fishery	2,09	0,06	0,12
6	Industrial fish fishery	-1,17	0,07	-0,08
	Liter of fuel per kg caught/landed mackerel ($DC_{Mackerel}$)			**0,06**

The diesel consumption per kg of mackerel is, $DC_{Mackerel} = \Sigma C_n \cdot DC_{n},$ where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

[27] System expansion is used when more than one useful product is generated by a process. The alternative production process for each by-catch, which is affected by the change in output from the codfish fishery, is included in the considered system in proportion to the way it is affected. Since subtracted fishing categories have by-catches as well, many fishing categories are involved in the system expansion and both negative and positive changes are observed.

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught Mackerel, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
$DC_{nMackerel}$: The fuel consumption for fishing category n – necessary to provide the output C_n.

Results

As it appears in last section the fuel consumption is estimated to **0,06 per kg caught mackerel**. Since mackerel is not gutted on board, the diesel consumption per kg landed mackerel is approximately equal to the fuel consumption per kg caught mackerel.

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels. For emission data see European Environment Agency (2001).

Technical scope

See app. 5.2 codfish.

Validation and representativeness

Validation
Tyedmers (2001) has analyzed the fuel consumption in German mackerel fisheries, involving four trawl vessels. His results suggest that the fuel consumption is 0,11 liter per kg mackerel, based on mass allocation. However, the fishery has a by-catch of herring, sardine and pilchard, that is not estimated.

As mentioned Tyedmers (2001) also have an average figure for small pelagic fisheries that suggest 0.062 liter per kg fish, based on mass allocation. The catch composition in this study was capelin (37%), herring (27%), blue whiting (15%), sand eels (8%), mackerel (5%), and Atlantic menhaden (4%).

The present study reaches 0,06 liter per kg mackerel applying both system expansion and mass allocation. This figure appear to be in good agreement with the average for small pelagic fish as observed by Tyedmers, but slightly smaller than for German mackerel fisheries. The difference can be explained by differences in species composition, catches area and fishing methods as well as uncertainties in the model Tyedmers use to estimate the fuel consumption, as explained in the section about herring fishery.

Concerning uncertainties related to estimates of the difference in fuel consumption between herring and mackerel fisheries see section 5.8 about herring fishery.

Representativeness

More than 99% of Danish mackerel fishery has been included and the data provides an almost complete coverage of the Danish fishery – see chapter 4.1. However the category herring and mackerel have been subdivided. Therefore fuel consumption specifically associated with mackerel fishery has been estimated on the basis of interviews with 5 pelagic trawlers and 3 purse seiners. Thus, the coverage in terms of fuel consumption for mackerel fishery is only 15%, as mentioned earlier.

A5.10 Industrial fish - fishery

Industrial fish refers to fish or landings from fisheries directed towards production of fishmeal and –oil (Muus and Nielsen, 1998). The industrial landings in Denmark consist mainly of Sandeel (50%). However, there are also considerable landings of Norway pout, blue whiting and Atlantic horse mackerel, sprat and herring (Fiskeriøkonomisk Institut, 2002).

Figure 9. *Tobis the most important industrial fish (Petersen, 2002)*

Resource situation. The fishery after industrial fish are restricted through quota on the most important species such as Tobis, but the fishing mortality is very low and the resource situation is far from critical.(Petersen, 2002)

Fishing grounds. The fishery after industrial fish is concentrated in the North Sea, but some are also caught in Skagerak. The target fish lives on depths from 10 to 100 meter.

Seasons and use. The fishery after Sandeel takes place from Marts to July, while Norway pout and other industrial fish are caught in the rest of the year. Industrial fish are by definition used in fishmeal and –oil production.(Fiskeridirektoratet, 2001a)

Process description

71 % of industrial fish are caught in regular industrial fish fishery (Fishing Category 6) with only limited by-catches. The remaining 30% are primarily caught in prawn and shrimp fishery (Fishing Category 7a) - see fishing categories (Fødevareøkonomisk Institut, 2002b).

The average size of Danish vessels catching industrial fish was 369 GT in 1999. The most common fishing gear applied in fisheries targeting industrial fish is trawl (98) and Pair trawl (2%). In both cases the trawl is typically bottom trawl, which have a light contact with the Sea floor, see appendix 2 (Hansen, 2002).

Processes included
See app. 5.2 codfish.

Product flow
Industrial fish are not handled on the Sea, but typically stored in Refrigerated Sea Water (RSV) tanks, which cause emissions of blood water. The energy for cooling of the seawater, comes from the ship engines and is a part of the overall energy consumption.

Other aspects related to product flow are similar to the situation for codfish – see app. 5.2.

Data collection and treatment

Data on catches and fuel consumption are based on fishermen's records and obtained by interviews and databases, see appendix 5.1.

Exchanges associated specifically with industrial fish - fishery have been determined from Fishing Category 6 "Industrial fish fishery". By-catches have been eliminated by system expansion[28]. The table below shows the result of the system expansion, in terms of the changes in total catch (C) from each fishing category (n) necessary to catch 1 kg of industrial fish. For further details see excel file on the CD (app. 5 document C).

[28] System expansion is used when more than one useful product is generated by a process. The alternative production process for each by-catch, which is affected by the change in output from the codfish fishery, is included in the considered system in proportion to the way it is affected. Since subtracted fishing categories have by-catches as well, many fishing categories are involved in the system expansion and both negative and positive changes are observed.

Table 12. *Necessary outputs and fuel consumption for each fishing category necessary to provide one kg of industrial fish.*

Fishing category		C_n (kg)	DC_n (l per kg)	$DC_{nIndustry}$ (liter)
No.	**Name**			
1	Codfish fishery	0,00	0,37	0,00
2 and 3	Flatfish fishery	0,00	0,63	0,00
7a	Prawn fishery	-0,01	0,17	0,00
7b	Shrimp fishery	0,00	1,03	0,00
4	Norway lobster fishery	0,00	1,56	0,00
7a	Mussels fishery	0,00	0,01	0,00
5a	Herring fishery	-0,06	0,12	-0,01
5b	Mackerel fishery	0,00	0,06	0,00
6	Industrial fish fishery	1,08	0,07	0,07
	Liter of fuel per kg caught/landed Industrial fish ($DC_{Industry}$)			**0,06**

The diesel consumption per kg of industrial fish is, $DC_{Industry} = \Sigma C_n \cdot DC_n$, where DC_n is fishing category n's diesel consumption per kg catch (l/kg).

C_n: The total catch from fishing category n – necessary to provide an overall output of on one kg of caught Industrial fish, from the whole fishing fleet.
DC_n: The fuel consumption per kg mixed fish in fishing category n
$DC_{nIndustry}$: The fuel consumption for fishing category n – necessary to provide the output C_n

Results

As mentioned the fuel consumption is estimated to **0,06 liter per kg industrial fish**. Since the fish are not gutted on board, the diesel consumption per kg landed industrial fish is approximately equal to the fuel consumption per kg caught fish.

Emissions to air from fishing vessel's diesel engines can bee estimated by multiplying diesel consumption with emission factors specific for European fishing vessels. For emission data see European Environment Agency (2001).

Technical scope

See app. 5.2 codfish

Validation and representativeness

Validation

Tyedmers (2001) estimated that the average fuel consumption is 0.062 liter per kg landed mixed small pelagic fish, using mass allocation. The catch composition in Tyedmers study was capelin (37%.), herring (27%.), blue whiting (15%), sandeels (8%), mackerel (5%), and Atlantic menhaden (4%).

Another Danish Study (made as part of the LCAfood project) found that the diesel consumption for Sandeel fishery in Denmark was 0.049 liter diesel per kg sandeel. This number is a little smaller but the difference can be explained by the fact that sandeel fishery is a very effective fishery, and that industrial fishery in certain periods are forced to target other species, which are considerably more energy demanding to catch. (Worck, 2002a). In other words the present figures are in good agreement with other studies.

Representativeness

As for codfish – see section 5.2.

A5.11 Overview of results

This section provides the reader with an overview of the results. This fuel consumption for all the species is shown in figure 13. In addition to the results based on system expansion, it is shown what results would have been according if applying mass and economical allocation. Furthermore, the table illustrates the absolute levels as well.

Table 13: *Absolute and relative fuel consumption for nine species calculated on the basis of mass allocation, economical allocation and system expansion.*

	Demersal fish		**Shell fish**				**Pelagic**		**Ind.**
Species	Codfish	Flatfish	Prawn	Shrimp	Norway lobster	Mussels	Herring	Mackerel	Tobis etc.
Landing volume (1000 ton)	68	41	6	3	5	110	135	34	68
	Relative fuel fouling input (Liter per kg fish)								
Mass allocation	0,47	0,56	0,54	1,02	1,16	0,01	0,14	0,08	0,10
Economical allocation	0,86	0,92	0,89	1,22	3,95	0,08	0,07	0,27	0,04
System expansion	0,36	0,97	0,76	1,03	6,05	0,01	0,18	0,06	0,06
	Absolute fuel input (1000 liter)								
Mass allocation	31.780	22.754	3.115	2.629	5.864	1.378	19.009	2.891	107.692
Economical allocation	58.245	37.565	5.068	3.149	19.929	8.233	9.791	9.263	45.870
System expansion	24.460	39.630	4.354	2.664	30.539	1.365	24.253	1.916	67.930

Mass allocation

Mass allocation can be performed differently depending on the purpose (see). The results presented here are calculated the following way. First, I have established the fuel consumption per kg mixed fish in each fishing category. With codfish as an example I have subsequently multiplied the amount of codfish in each fishing category with the corresponding fuel consumption per kg mixed fish (in each category) and summed up the results providing the figure for the total fuel consumption for all codfish in the whole fishery. As I know the total catch of codfish, the relative fuel consumption is established as the total fuel consumption for codfish divided with the total catch of codfish measured in mass. A similar procedure is used for the other species. The results are validated with the total fuel consumption and there is no discrepancy.

Mass allocation may also perform on the whole fishery without considerations of fishing categories. This is simply the whole fuel consumption divided with all the catches. The fuel consumption then becomes 0,13 liter per kg fish for all species.

I have used mass allocation in yet another way, focusing on the fishing categories separately. This is further explained on the CD app. 5 document C. The bottom line is that the first method (represented by the results in the table) is the most accurate.

Economical allocation

In regard to the results based on economical allocation, the allocation key is, the total value of a given species (A) divided with the value of all species in the whole fishery. This percentage is multiplied with the fuel consumption for the whole fishery. The figure now obtained represents the fuel used for the given target species. Finally, this figure is divided with the total catches of the given target species (A) – which provides the final result in liter per kg for species (A). This procedure should ideally have been performed individually in each fishing category, but as the catch value has not been available at this level of detail, this has not been done.

App. 6: Antifouling & Species (fishery)

The energy consumption for nine species, were analyzed in appendix 5 (document C). In this chapter the focus is anti fouling agents related to the same nine species. The principles for data treatment are similar to those carried out in app. 5 and is based on the fishing categories described in app. 5.1.

The focus in this chapter is not energy consumption, but anti fouling agents, which is proportional with the size of the ships. Therefore, the fist sections will deal with adjustments of the fishing categories, and the corresponding adjustments to average vessel size in each fishing category. Subsequently, the focus will be empirical data that correlates vessel size and consumption of anti fouling agents. On this basis it is possible to establish data for the average emissions per kg mixed fish in each fishing category.

From app. 5 we already know how much output we need from each fishing category to produce a given output from all fishing categories e.g. one kg of codfish. Hence, by multiplying the necessary output with the estimated emissions per kg mixed fish in each category it has been possible to establish the emissions per kg target fish in each of the nine species groups.

All sections follow the structure generally applied for descriptions in this dissertation:

6) Process description
7) Data collection and treatment
8) Results
9) Reliability and completeness.

A6.1 Process description

The process description is much similar to what has already been described in app. 5 in relation to energy consumption.

Processes included
It is basically the same processes that is included, but it should be stressed that the emissions calculated in this appendix refer to emissions that are released to directly to the sea water during the steaming and catch phase as well as when the vessel is in harbor.

Emissions or hazardous waste that is generated during maintenance of the vessel are not included, but described separately in chapter 3.

Product flow
See app. 5.2

A6.2 Data collection and treatment

Data sources

The data for catches and average vessel size are based on fishermen's records and have been collected by the Danish Institute for Food Economics. For further details see app. 5.1 and Fødevareøkonomisk Institut (2001b).

The adjustments in average vessel size that is carried out while expanding the original seven fishing categories to nine categories have been possible through additional datasets for vessel size in "clean fisheries". These data have been provided by Nielsen (2002b). Details regarding sample size etc. are described in the following sections.

The original seven fishing categories

As carefully explained in app. 5, the Danish Institute for food economics subdivides the Danish fishery in 7 fishing categories. I have chosen to estimate the amount of anti fouling paint on the basis of the tonnage of the vessels in the fishing categories – arguments will follow. The average tonnage in the seven original fishing categories is illustrated in table 1.

Table 1: *Tonnage and catch data for fishing vessels in the 7 original fishing categories (Fiskeriøkonomisk Institut, 2001b)*

Fishing Category	**No. 1**	**No. 2**	**No. 3**	**No. 4**	**No. 5**	**No. 6**	**No. 7**
	Codfish	Codfish/ flatfish	Flatfish	Norway Lobster	Pelagic	Industrial fish	Mixed fish
Average size of vessels	16	25	40	46	620	329	57
	Catches (kg)						
Codfish	68.779	50.328	13.943	30.128	19.595	11.259	37.763
Flatfish	7.979	30.851	83.469	16.870	189	2.952	18.767
Norway lobster	136	164	57	19.648	257	102	3.088
Herring/ mackerel	14.576	199	2	3.382	3.980.377	250.161	108.700
Industrial fish	6.367	23.552	6.571	17.199	4.305.760	8.265.482	485.861
Mixed	31	338	119	8.677	36	1.380	265.318
Other edible fish	844	977	1.710	5.270	81	713	14.316

Modification of fishing categories

The data on catches and tonnage for the original seven fishing categories, mentioned in previous section, are based on fishermen's records and have been collected by the Danish Institute for Food Economics. Fødevareøkonomisk Institut (2001b).

As mentioned in app. 5, the original fishing categories have been slightly modified. Fishing category five is modified to (5a and 5b) and fishing category seven becomes (7a, 7b and 7c). Furthermore, two categories are merged, thus category 2 and 3 are modified to (2a). This means that we end up having 9 fishing categories, representing 9 groups of species. The tonnage in each category has been modified accordingly, based on mass balances and additional data for clean fisheries.

Adjustments for herring and mackerel

For herring and mackerel the tonnage have been distributed after the same allocation key as the fuel consumption. The argument is that the fuel consumption is proportional to the number of sea days and that the number of sea days is proportional with the consumption of anti fouling agents. We know that herring is typically caught by smaller vessels (390 GT) than mackerel (568 GT) see. App. 2. However, we don't consider the whole fishery here, but only fishing category five. For fishing category five it is assumed that all vessels catch both herring and mackerel and I assumed that the vessels are the same size (620 GT).

Adjustments for blue mussels

For blue mussels I have established a sample of 6 mussel vessels with an average tonnage of 7 GT (Nielsen, 2002b). This has been used to estimate the average tonnage in this segment. In app. 2 it appears that the average tonnage for mussels is 14 GT. However, I consider clean mussel fishery and therefore use the 7 GT instead of 14 GT. This may be an underestimation. The result is that the amount of anti fouling may be a little overestimated, as an smaller average tonnage per vessel gives a higher consumption of anti fouling per kg fish – explanation follows.

Adjustments for shrimp

For shrimp I have used the same procedure as for mussels. The sample considers 6 vessels with an average tonnage of 27 GT. As it appears in app. 2 the average tonnage for shrimp and prawn fishery is 147 GT. Another sample of prawn fishery considering 9 vessels show that the average tonnage here is 177 GT (Nielsen, 2002b). Thus, it seems reasonable that clean shrimp fishery have a tonnage of only 27 GT, because it is a completely different fishery, taking place in shallow water – see app 5.6.

Tonnage in adjusted fishing categories

On the basis of this procedure I have established a picture of the average tonnage in 9 fishing categories (table. 2)

Table 2. *Average number of vessels and tonnage per vessel in the nine adjusted fishing categories*

	Demersal fish		**Shell fish**				**Pelagic**		**Ind.**
	1	2a	7a	7b	4	7c	5a	5b	6
Fishing category	Codfish	Flatfish	Prawn	Shrimp	Norway lobster	Mussels	Herring	Mackerel	Tobis etc.
Number of vessels (units)	370	419	346	26	182	67	23	23	96
Average tonnage (GT)	16	31	68	27	46	7	517	103	329

Correlation between vessel size and anti fouling agents

It is obvious that large vessels have a larger consumption and emission of biocides compared to small vessels. The Gross Tonnage (GT) is one way to measure for the size of a vessel, and may therefore be used to estimate the absolute biocide emissions from a vessel. However the surface area of the hull is not directly proportional with the tonnage. In fact, small vessels will typically have a large surface area per tonnage compared to large vessels. To establish a correlation between the amount of anti fouling agent and vessel sizes I have gathered data for different sizes of vessels.

Empirical data

Concerning steel vessels used in the North Sea and the inner Danish waters the primary source is a slipway called “Karlssons Bedding” in Hirtshals (Mikkelsen, 2001). The data represents different sizes of vessels, which have been painted with Sigmaplane HA Antifouling 7287 in 1999. All the vessels are normally painted one time per year. According to Bent Mikkelsen, the slipway uses approximately the same quantity of paint whether the brand is Hempel, Sigma, or other modern anti fouling paints containing tin and copper compounds. It may however vary up to 10% - according to him. The quantity may also vary as a function of the condition of the hull, but if the different vessels are painted once a year the variation in the condition will probably me minor, he states. The amount of anti fouling paint per length and GT from six steel vessels painted at Karlssons Bedding is illustrated below (Figure 1)

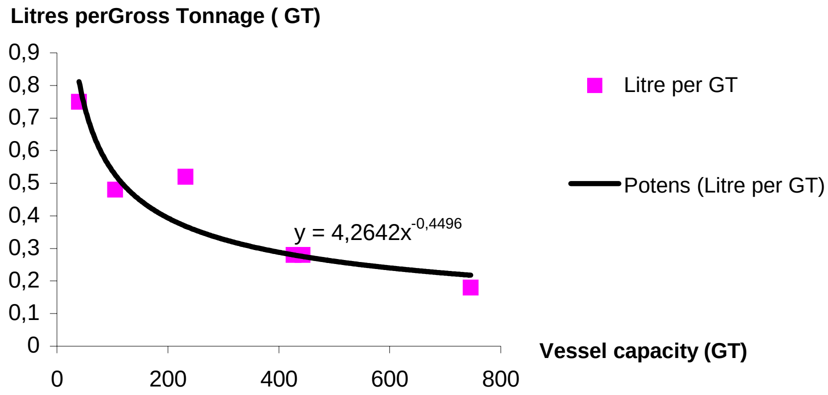

Figure 1: *The amount of anti fouling paint per length and GT from six steel fishing vessels painted with Sigmaplane HA Antifouling 7287 one time per year at Karlssons Bedding in Hirtshals (Mikkelsen, 2001)*

On the basis of this information and personal communication with Hempel, it is assessed that the amount of paint will vary less than 30% between ships with the same tonnage, painted once a year[29].

As illustrated the best-fit line[30] between GT and liters of paint shows that the amount of paint per GT decreases as a function of the size of the vessels.

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[29] These figures and assumptions have been discussed with Hempel, which is one of the leading producers of anti fouling agents in the world. The environmental manager, Martin Porsbjerg, confirms that the numbers and assumptions are reasonable for establishing a rough estimate of the proportionality between GT and liters of anti fouling agent used on fishing vessels. However he emphasizes that the actual amount of anti fouling agent depends on a long series of parameters such as the physical shape and condition of the vessel, the expected average speed, activity level, salinity of the water, service frequency, consumption factor for application etc. (Porsbjerg, 2002).

[30] It is assumed that the best-fit line is an exponential function. The shape of a vessel can roughly be compared to a cylinder. The equation for surface area divided with volume of a cylinder is 2/r, where r is the radius in the circle. This means that the surface area per volume becomes relatively large for small vessels. Martin Porsbjerg from Hempel also considers this assumption to be reasonable for the purpose of this report.

Additional data for small wood vessels

There is also obtained data for small wood vessels operated in the North Sea and the inner Danish waters (Slipway, 2001). The data represents average wood vessels painted with Hempel Antifouling Bravo 76100 one time per year. The amount of anti fouling agent per GT varies from 0,8-0,6 liter per GT for vessels between 10 and 60 GT, where the largest consumption is for the small vessels. Interview with 2 mussel fishermen (also wood vessels) suggest a yearly consumption of anti fouling agent, around 20 liter for vessels between 8 and 15 GT, which gives a consumption between 1,3 and 2,5 liter per GT. Thus, for small vessels the variations appear to be high.

Extra uncertainty for very small and very large vessels

The previous data from Mikkelsen (2001) suggest that 10 GT stell-vessels consumes between around 1,5 liter per GT, while 60 GT vessels consume only 0,7 liter per GT. This is not far from the observations above, but still it is must be considered that the uncertainty is probably large for very small and very large vessels, outside the area of actual measurements.

Correlation between consumption and emissions

On the basis of the function in figure 1, it is not possible to estimate the number of liter used for vessel of different sizes. However, the emissions are not equal to the consumption. Some of the paint is scraped off on the slipway when new paint is added, and some may stay on the hull under the new layer of paint. According to Martin Porsbjerg from Hempel a rough estimate is that around 2/3 of the anti fouling agents are released during use. (Porsbjerg, 2002)

Emissions per kg caught mixed fish

The average emissions per kg caught mixed fish in each category are illustrated in the table below.

Table 3. *Emissions per kg caught mixed fish in each fishing category.*

	Demersal fish		Shell fish				Pelagic		Ind.
	1	2a	7a	7b	4	7c	5a	5b	6
Emissions of anti fouling	Codfish	Flatfish	Prawn	Shrimp	Nor. lobster	Mus-sels	Her-ring	Mack-erel	Tobis etc.
ml / kg caught mixed fish	0,13	0,18	0,04	0,16	0,23	0,01	0,01	0,02	0,01

Exchanges associated specifically with the different species can be determined the same way as for fuel consumption, by system expansion. The amount needed from each fishing category is exactly the same as for fuel. For further details see the CD (app. 5 document C).

A6.3 Results (overview)

Following the same procedure for allocation, as used for energy consumption, I have established an overview of the emissions of anti fouling related to the catch varies species. The data and calculations are described in the excel file on the CD (app. 5 document C).

Table 4: *Absolute and relative emissions for nine species calculated on the basis of mass allocation, economical allocation and system expansion. See the excel file on the CD (app. 5 document C)*

	Demersal fish		Shell fish				Pelagic		Ind.
Species	Codfish	Flatfish	Prawn	Shrimp	Nor-way lobster	Mus-sels	Her-ring	Mack-erel	Tobis etc.
Catch volume (1000 ton)	68	41	6	3	5	110	135	34	68
	Relative anti fouling emissions (ml per kg caught fish)								
Mass allocation	0,12	0,14	0,08	0,16	0,17	0,01	0,02	0,02	0,01
Economical allocation	0,12	0,13	0,13	0,17	0,56	0,01	0,01	0,04	0,01
System expan-sion	0,15	0,24	0,43	0,16	0,50	0,01	0,02	0,02	0,01
	Absolute anti fouling emissions (liter)								
Mass allocation	7.993	5.509	476	406	881	555	3.175	630	16.277
Economical allocation	8.287	5.345	721	448	2.836	1.171	1.393	1.318	6.526
System expan-sion	10.370	9.924	2.457	403	2.500	552	3.031	803	8.143

As it appears the emission varies between 0,01 and 0,56 ml anti fouling paint per kg caught fish, depending on the species and allocation method. The excel file on the CD (app. 5 document C) include a thorough description of the calculations based on mass allocation, economical allocation and system expansion.

Table 4 only contains information about the emissions of anti fouling agents without regarding the composition of the agents. Hence, in order to calculated the elementary flows it is necessary to use data for chemical composition, described later in this appendix.

A6.4 Scope

The time, geographical and technological scope is similar to what has already been described in app. 5 concerning energy consumption.

Concerning time scope it is important to stress that current anti fouling agents containing TBT will be replaced with other and probably less harmfull agents.

Concerning the future it is not likely that we will se a significant change in the amounts of anti fouling that is used – at least it is very difficult to say. It is easier and more relevant to consider the toxicity level. The Danish EPA has the goal of being able to prohibit any toxic paints by 2006, but it is still uncertain whether this is possible. Nevertheless, it is almost certain that the toxicity level of the paints used will decrease in the years to come. Whether there will be a gradual change or a technology jump is difficult to say. I have therefore developed different scenarios concerning the toxicity levels.

TBT scenario (business as usual)
TBT has been among the most used and most effective anti fouling agents during recent years. However, it is gradually being replace by other paints, because of international regulations – see chapter 4.

The question is, how much TBT that are released per liter of anti fouling agent emission. According to Swedish National Chemical inspectorates homepage, TBT based anti fouling agents typically contain copper(I)oxide (Cu_2O) together with Tributyltinoxide (TBTO) and Tributyltin-methacrylat co-polymer. Hempels anti fouling paints termed Nautic SP-ACE 79031 and 79051, that are now illegal, would be a typical representative for this group of paint. The contents of biocides are (Swedish National Chemicals Inspectorate, 2002):

- Copper(I)oxide (Cu_2O): 43-46 % w/w
- Tributyltinoxide (TBTO): 0,6 % w/w
- Tributyltin-methacrylat co-polymer: 10-13% w/w

As the gravity of these paint is 1,7 kg per liter, we can calculate the amounts per liter (Porsbjerg, 2002)

- Copper(I)oxide (Cu_2O): 731-782 gram per liter
- Tributyltinoxide (TBTO): 10,2 gram per liter
- Tributyltin-methacrylat co-polymer: 170-221 gram per liter (eqv. 85-111 gram TBT[31])

However, the emission is smaller as it is only some of the A/F that are released to the water during fishing and in the harbor. A rough estimate is that it is only 2/3 of the active agents that released to the water (Porsbjerg, 2002).

In the EDIP database the eco-toxicity factor for TBT is estimated to (Stranddorf et al., 2001):

- $1{,}03 * 10^5$ m^3 per gram (water acute)
- $1{,}03 * 10^6$ m^3 per gram (water chronic)

This means that the water volume that we need to dissolve on gram of TBT to reach a predicted no-effect concentration is bigger for chronic eco-toxicity than for acute eco-toxicity. In other words the long-term effects should definitely be considered in this case[32].

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[31] Tributyltin-methacrylat is a co-polymer with a sequence ABABABAB. One sequence AB contains one TBT unit. According to Hempel they use tributyltinmethacrylate / methyl methacrylate in the mol relationship, 1:2. Hence, 50% of the copolymer is TBT (Porsbjerg, 2002).

[32] According to Romhass (2002) the acute and chronic eco-toxicity for TBT is: 2-10 $*10^{-6}$ gram per liter (water acute) and 0,001-0,01 $*10^{-6}$ gram per liter (water chronic). This supports that the chronic eco-toxicity is the most important. It is not explained how these values are established and whether they represent NOEC, LOEC, LC 50 or similar. Thus, it is difficult to estimate the PNEC value and the eco-toxicity factor on the basis of these figures. Therefore, I have chosen to rely on the eco-toxicity factors from the EDIP method.

The EDIP method estimated the eco-toxicity factor for cobber to (Stranddorf et al., 2001):

- 1,3 * 10^3 m^3 per gram (water acute)
- 1,3 * 10^4 m^3 per gram (water chronic)

This also shows that the chronic effects definitely are worth to consider in this case[33].

A large number of toxicity and risk assessment studies have been done for both cobber and TBT, but still there is a relatively large uncertainty – especially for cobber. According to Ranke and Jastorff (2000), the risk profile of TBT and cobber compounds is as follows:

Table 5. *Risk profile for TBT and cobber compounds. High numbers signifies high risk scores. Maximum is 4 and minimum is 0. Letters behind the numerical scores represents the uncertainty of the judgment, where" a" is the lowest and "d" the highest uncertainty. (Ranke and Jastorff, 2000).*

	Release rate	Spatiotemporal range	Bioaccumulation	Biological activity	Remaining uncertainty
TBT acrylate	2a	2b	4a	4a	1
Other TBT compounds	3b	2b	4a	4a	1
Cobber acrylate	3d	3d	3a	3c	3
Other cobber compounds	4c	3d	3a	3c	3

As the table shows the uncertainty is generally high for cobber compounds. It also appears that TBT has a high bioaccumulation and biological activity (Ranke and Jastorff, 2000). Even though the study suggest that TBT has the worst risk profile – cobber also appear to be a substance with a serious toxicity potential – especially considering the large uncertainties.

[33] According to Ranke and Jastorff (2000) the PNEC for cobber-oxide (Cu_2O) is at least one order or magnitude higher than TBT, which is in good agreement with the figures suggested by the EDIP method.

Sea nine scenario (Best Available Technology)
Sea nine is the name of a biocide that is used in Hempel's new series of anti fouling paints called Globic. Sea nine (4,5-dichloro-2-n-octyl-4-isothiazolin-3-one inxylene) is Hempel's new alternative to the TBT paints that are being phased out, as a consequence of regulation. Sea nine is produced by Rohm and Haas, and is chosen because of its lower persistence in the environment and lower toxicity towards humans in comparison with TBT.

The company have achieved the "presidential green chemistry award" of the US EPA in the category "Designing safer chemicals". Nevertheless, sea nine 211 is subject to some restrictions in Sweden and has the same regulatory status as the biocide diuron (Ranke and Jastorff, 2000)

On the homepage of the Swedish Chemical inspection, it is shown that the content of biocide in a typical paint (e.g. Globic SP-ECO 81-920) based on sea nine is the following:

- Copper(I)oxide: 39,5 % w/w
- Sea nine: 1,9 % w/w

As the gravity of the paint is 1,9 kg per liter, this is equivalent to:

- Copper(I)oxide: 751 gram per liter
- Sea nine: 361 gram per liter

Again, we should consider that it is only around 2/3 of the paint that is released to the water.

According to Romhass (2002) the toxicity for Sea nine is:

2-10*10^{-6} gram per liter (water acute)
0,6-6*10^{-6} gram per liter (water chronic)

As mentioned Romhass does not explain exactly how the figures are derived and what they represent. However, the acute toxicity is the same for TBT and sea nine. As we know, the eco-toxicity factor for TBT it must be assumed that it is roughly the same for sea nine, which is 1,03* 10^5 m^3 per gram (water acute). For chronic eco-toxicity (water) sea nine is estimated to be around 600 times less toxic compared to TBT according to Romhass (2002). Again we know the eco-toxicity factor chronic water for TBT from the EDIP method and the respective eco-toxicity for sea nine can be estimated by multiplying with 600. This is $1,03*10^6$ m^3 per gram (water chronic) divided with 600, which is $1,72*10^3$ m^3 per gram (water chronic)

Concerning the toxicity for cobber – I will refer to last section, TBT scenario.

Compared to TBT there are only few studies of eco-toxicity related to Sea nine. The uncertainty is therefore large – similar to that of cobber. The Risk profile of Sea nine is illustrated below:

Table 6.. *Risk profile for sea nine 211. High numbers signifies high risk scores. Maximum is 4 and minimum is 0. Letters behind the numerical scores represents the uncertainty of the judgment, where "a" is the lowest and "d" the highest uncertainty.(Ranke and Jastorff, 2000)*

	Release rate	Spatiotem-poral range	Bioaccumu-lation	Biological activity	Remaining uncertainty
Sea nine 211	2d	3c	3c	3d	3

As it appear Sea nine is better concerning bioaccumulation and biological activity, while the spatiotemporal range comes out to be worse. Apart from that the uncertainty is a great deal larger, and even though the PNEC values are considerably lower – the risk profile as well as Swedish regulations on sea nine, draws a picture of a chemical that is still problematic.

Future cobber scenario (Best Possible Technology)

In a new proposal for regulation of anti fouling agents the Danish EPA suggest that the paints must have a content of cobber(I)oxide that is less than 10% w/w. There exist numerous studies of the toxicity of cobber in the water compartment - and the concentrations in the Danish waters are continuously measured. These measurements show that 40% of the mussels in Kattegat and Skagerak are clearly influenced by high cobber concentrations (Miljøstyrelsen, 2002a). If it is assumed that it is possible to develop effective paints with a cobber content under 10% w/w, without any booster chemicals and if these paints will be widely used within the fishery, we have a scenario that suggest the following content of biocides:

- Copper(I)oxide: ~10% % w/w

If we assume that the density of these paints is 1,5-2 kg per liter, the cobber content per liter will be:

- Copper(I)oxide: 150-200 gram per liter

Again we should consider that it is only around 2/3 of the paint that is released to the water. PNEC values and risk profile for cobber is described in the TBT scenario.

A6.5 Validation and representativeness

Validation

It has not been possible to establish a figure for the total consumption of antifouling agent in the Danish fishery. Thus, is has not been possible to verify the results based on knowledge about the aggregated consumption for the whole fleet, like for fuel consumption. This is clearly a weakness.

Other case studies
On the case specific level a Swedish LCA study of cod, estimated that the amount of consumed anti fouling was 0,5 ml per kg landed codfish (Ziegler, 2002). Applying the same correlation factor for emissions per consumption, as the present dissertation, this is similar to an emission of 0,33 ml per kg landed codfish. As mentioned, the present dissertation estimates an emission of 0,15 ml per kg caught codfish based on system expansion, which is similar to 0,18 ml per kg landed codfish. Hence, Zieglers figures are still a factor of 2 higher. The difference is difficult to explain but several factors come in to play. First of all, it is not the same type of paint that is used. The content of biocides and the density is different, thus influencing the result. Apart from that the vessels operates in different kind of waters with different salinity etc. Finally, the Swedish study considers cod while the present study considers codfish.

Verification of correlation factor
The empirical data that correlates the vessel size measured in GT, and the consumption of anti fouling agents has been verified by one of the largest producers of anti fouling agents. In this regard it has been established that the consumption may vary up till 30% depending on the specific type of paint, vessel size, shape and condition, the environment in which the vessel operates and other factors.(Porsbjerg, 2002). As other factors of uncertainty are involved as well - such as the emission factor and the allocation between

species - it is assumed that the results for emissions per target fish has a uncertainty of 50%.

Additional uncertainty for very small and large vessels
As mentioned, the data concerning amounts of anti fouling agents have a extra degree of uncertainty, when estimated on basis of extrapolation of the data in figure 1. This is especially the case for codfish and mussels where the average tonnage is 16 GT and 7 GT respectively.

Representativeness

Concerning the tonnage in each fishing category than 99% of Danish fishery has been included and the data provides an almost complete coverage of the Danish fishery. For further details see app. 5.1.

Additional empirical data for tonnage in adjusted fishing categories
There have been used additional data for adjustment of fishing categories. In this respect, there have been used a sample of 6 vessels to determine the average tonnage for clean mussel fisheries. There have been used a sample of 6 vessels to determine the average tonnage in clean shrimp fisheries as well and finally 9 vessels have been used to determine the average tonnage in prawn fisheries. The latter is only used indirectly, as explained. For herring and mackerel it is assumed that the vessels in fishing category 5 a and 5 b have the same size. These additional data are far less complete and the completeness for data related to herring, mackerel, shrimp, prawn and mussels must therefore be assumed to be slightly smaller than for other species groups.

Empirical data for correlation between size and anti fouling agents
There have also been used additional empirical data to establish the correlation between vessel size and consumption of anti fouling agents. In this respect the analyze is based on a sample of six steal vessels in different size categories. The completeness in this analysis is also relatively small, but this has been compensated by verification made by one of the largest producers of anti fouling agents in the country (Porsbjerg, 2002)

All things considered, it is assessed that the data collection is relatively complete and represents average Danish fishery in year 2000.

App. 7: Transport Data

This appendix describes calculations and assumptions used for the analysis of exchanges at the transport stage in chapter 6.3. The focus in this appendix is exchanges of energy.

A 7.1 Energy consumption

Export destinations for product groups

To be able to estimate the energy consumption it has been necessary to establish a picture of the transport load, through an export analysis.

Concerning the countries to which different types of fish products are exported, it was established that south Germany could be used as an average distance to the market for a typical Danish fish product, in chapter 2. For the three most important product groups of processed fish the export destinations are the following – percentages are per volume (Fiskeridirektoratet, 2001a):

- Filets: Germany (45%), France (15%), UK (8%) and Sweden (5%)
- Salted and smoked: Germany (34%), Italy (24%), Holland (14%) and Spain/Portugal (7%)
- Prepared and conserved: Germany (34%), UK (13%), Sweden (12%) and France (10%).

For unprocessed products the destinations are the following.

- Whole saltwater fish: Norway (22%), Holland (16%), Germany (14%), and France (9%).
- Shellfish: Germany (23%), Sweden (10%), France (8%) and Japan (8%).

For specific fish species the distribution can be a little different from the pattern above. This is further analyzed in the following.

Markets for codfish products

As explained in chapter 2, it is by far the largest meat volume for cod that is exported as frozen or fresh filet.

For fresh filets the main export countries are Germany (25%), Italy (19%), Spain /Portugal (19%) and France (11%). For frozen filets, which is a similar amount measured in meat content, the most important export countries were UK (41%), France (13%), Germany (11%) and Sweden (10%). Sweden is closely followed by US with 7%.

For salted and smoked cod products the most important markets were Italy (48%), Spain/Portugal (32%) and France (18). For breaded products the most important markets were Germany (40%), France (14%), Sweden (13%), Switzerland (12%) and Holland (4%). For ready made dinners the markets were Germany (21%), UK (17%), Switzerland (15%), Sweden (12%), Norway (9%), Holland (5%) and France (5%).

For whole cod the largest export is fresh fish. The main export markets for fresh whole cod are France (36%), Holland (21%), UK (12%) and Spain and Portugal (11%). For frozen whole cod the export countries are Spain/Portugal (23%), Poland (18%), Germany (7%), France (6%) and Holland (4%). Even though there have been included many countries here, it has not been possible to achieve 80% of the export because there apparently miss some figures in the statistics.

Markets for flatfish products

As explained flatfish are also mainly exported as whole fish – see chapter 2. For whole flatfish, there is a significant export of both fresh and frozen fish. For the fresh whole flatfish, which is a huge export, the main export countries are Holland (63%), Germany (12%), Spain/Portugal (6%) and France (4%)

For the frozen whole flatfish, which is lees than half of the export of fresh whole flatfish, the main export countries are Japan (28%), Germany (27%), Taiwan (22%) and Spain/Portugal (6%)

There is barely exported any fresh flatfish filets, but for frozen filets the most important markets are UK (29%), Germany (15%), Sweden (15%), Italy (13%) and Switzerland (8%)[34].
Similar to codfish, flatfish are also sold as breaded filets or ready made dinners. As it is assumed that 10-15% of the products are based on flatfish, the amount is similar to the amount of frozen filets. The most important export countries are mentioned under codfish – further details in chapter 2.

Markets for shellfish products

As described in chapter two the largest proportion of lobster ((Norway- and European lobster) is exported as whole fresh or frozen lobster. The largest markets are Italy (62%), Spain/Portugal (10%), France (8%) and UK (2%). It cannot bee established how much that is exported as processed.

For shrimps there is exported a nearly equal amount of whole shrimps and prepared/canned shrimps – in terms of meat content. For whole shrimps the most import markets are Sweden (16%), Japan (11%), France (11%), Russia (9%), Norway (7%), Holland (6%), UK (3%), Italy (3%), Thailand (2%), Spain/Portugal (2%). Even though there have been included many countries here, it has not been possible to achieve 80% of the export because there apparently miss some figures in the statistics.

For prepared and canned shrimps UK (24%), Italy (20%), Germany (19%), Sweden (15%), France (4%) and Spain/Portugal (3%).

For mussels, it is by far the largest proportion that is exported as prepared or conserved, in terms of mussel meat. The largest markets are France (44%), Germany (11%), Holland (11%), UK (10%) and Sweden (7%). For unprocessed mussels the largest markets are Germany (88%), Holland (8%), UK (2) and France (1%)

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[34] According to the Transport manager at company flatfish the main export countries for frozen flatfish filet (plain and breaded) are Sweden, UK, Germany, Denmark, Italy, Switzerland and France. This is a more detailed picture than what can be achieved from the official fishery statistics (Company Flatfish, 2003b). However, it has not been possible to achieve information about the distribution among the countries – and therefore the data from the statistics have been used as the best estimate.

Markets for pelagic fish

In chapter two it was established that pickled herring and canned mackerel constitutes the largest volume in terms of meat compared to the other product categories. However, there is also a significant export of unprocessed herring and mackerel.

For prepared and conserved herring of which it is assumed that the largest part is pickled herring, the most important markets are Germany (72%), Holland (19%), Sweden (5%) and Poland (2%).

There is only a small amount of herring that are exported frozen whole, but for fresh whole the markets are Norway (57%), Germany (18%), Sweden (14%) and Holland (3%).

For prepared and conserved mackerel of which it is assumed that the largest part is canned mackerel, the most important markets are UK (31%), Germany (20%), Sweden (17%), Holland (6%), France (4%) and Japan (3%).

Whole mackerel is exported as fresh and frozen in similar quantities. For fresh mackerel the markets are Norway (87%), Italy (3%), Holland (1%) and Sweden (1%)

For frozen whole mackerel the markets were Japan (27%), Germany (11%), Sweden (5%) and Holland (5%). Nor has it been possible to achieve 80% of the export in this case, because there are missing some figures in the statistics, here as well.

Assessment of transport distances

It can be established that the European market by far is the most important market for most Danish fish products. For an average fish product south Germany can be used as an average distance to the market. The distance between Esbjerg or Frederikshavn and München is app. 1.100 – 1.300 km (Viamichelin, 2003). For a more detailed analysis I have divided the export distances in six categories:

- Domestic market (100-500 km)
- Scandinavia, such as Norway and Sweden (500-1.000 km)
- Central Europe and UK, such as Germany, France, Holland and UK (1.000-2.000 km)

- Southern Europe, such as Spain, Portugal and Italy
- (2.000-3.000 km)
- Cross continental, such as Asia, America etc. (<5.000 km)

Based on these categories and the previous market analysis it has been possible to establish a table, with information about the main market, the average export distance and the transport related direct energy demand[35], for a range of important Danish fish products. It should be noticed that the order of the products, also within species categories, reflects the importance of the export in terms of volume.

[35] The energy demand has been calculated on the basis of information provided by Niels P. Therkelsen, Adm. dir., Peter Hansen Transport A/S, Padborg. It has been informed that the transport of fish products is conducted by 40 tons trucks, with an average mileage of 3 km per liter fuel. The load capacity is 14-15 tons fish for fresh fish and 20 tons for frozen. For fresh fish (whole and filets) the tara is 40-50%. Tara means ice, fish cradles etc. For some trucks with a mixed load and a load of different sizes and shapes in packaging the capacity can be smaller. The truck returns to Denmark with a load of 90% of the max load. Hence, the energy consumption is respectively 0,63 MJ per tonkm for frozen products and 0,88 MJ per tonkm for fresh products (Therkelsen, 2003)

Table 1. *Main markets, average distances (one way) and estimated energy demand for Danish fish products in year 2000. In each category the export cover more than 80% of the total export, except from three cases*. Data for fresh products are with italic writing. Transport to cross continental destinations are not included in the average distances, but are discussed separately in the following (Fiskeridirektoratet, 2001a)*

	Domestic	**Scandinavia**	**Central EU**	**South EU**	**Cross cont.**	**Average dist.**	**Energy input**
Codfish	Percent	Percent	Percent	Percent	Percent	Km.	MJ / kg.
Fresh filet			36	48		2.071	*1,8*
Frozen filet		10	65		7 (US)	1.400	0,9
Whole fresh			69	11		1.638	*1,4*
Breaded		13	70			1.276	0,8
Salted & smoked			18	80		2.316	1,5
Ready made		21	63			1.313	0,8
Whole frozen*			35	23		1.897	1,2
Flatfish							
Fresh whole			79	6		1.571	*1,4*
Frozen whole			27	6	50(Asia)	1.682	1,1
Frozen filets		15	52	13		1.522	1,0
Breaded		(13)	(70)			1.276	0,8
Ready made		(21)	(63)			1.313	0,8
Shellfish							
Norway lobster			10	72		2.378	*2,1*
Whole shrimp*		16	20	5	22(Asia)	1.329	*1,2*
Shrimp (P/C)		15	47	23		1.638	1,0
Mussel (P/C)		7	76			1.437	0,9
Whole mussel			99			1.500	*1,3*
Pelagic fish							
Herring (P/C)		5	93			1.462	0,9
Whole fresh herr.		71	21			921	*0,8*
Mackerel (P/C)		17	61		3 (Asia)	1.337	0,8
Whole fresh mac.		88	1	3		815	*0,7*
Whole frozen mac*		5	16		26(Asia)	1.321	0,8

As illustrated the average transport distance varies from 815 km for whole fresh mackerel to 2.387 for lobster – nearly a factor 3. It appears that shellfish generally have a longer transport distance than the average product. Opposite, it appears that pelagic fish have a smaller transport distance than average.

Still, there are several aspects that are not considered in table 1: 1) extra packaging for some products which means more transport per kg fish, 2) extra transport if we include transport between different processing plants in

Denmark and 3) extra transport considering imported and re-exported products. Finally the table only looks at lorry transport within Europe. It does not consider export to transcontinental destinations, nor does it consider products sold on the domestic market as well as other modes of transportation such as train, ship and plain. All these aspects will be further analyzed in the following

1) Special cases with extra packaging
The amount of fish that can be loaded on each truck mainly depends on the amount of packaging, cradles and ice. Therefore the load capacity for fresh fish is 25% smaller than for frozen fish. This has been considered in table 1.

However, there are also products such as pickled herring and preserved or conserved mackerel and mussels, where the packaging constitutes a significant percentage of the weight. An extreme case is pickled herring in jar where the edible product only constitutes ¼ of the total weight. Hence, the energy consumption for *canned and preserved products can be up till four times larger*, than the numbers suggest in table 1, where the data for these products are calculated as if they were frozen. The analysis in chapter 6.3 includes packaging in table 2.

2) Extra transport between factories in Denmark
The analysis of average transport distances is calculated on the basis of rough estimates for 4 groups of destinations. The estimates do not include specific considerations about transport between different firms in cases where the production is split up, such as for pickled herring.

However, the uncertainties of the distances mentioned in table 1 are so large, that an additional detailed analysis of these marginal aspects would be meaningless. In this respect it should be mentioned that transport between harbor and processing is included at the processing stage.

3a) Production based on imported products
The focus of this dissertation is fish products, which are caught and processed in Denmark. Therefore it is only strictly necessary to address transport distances from Denmark to the market. Still, it is interesting to elucidate how much that is left in this scope.

It is obvious that some products are imported as whole fish or semi-manufactured products. The total import of fish to Denmark is in the same order of magnitude as the total landings in Danish harbors. Considering edible fish, the largest import measured in meat content, is non-processed fish, as the volume is nearly four times larger than the import of processed products. Import of non-processed or semi-manufactured fish products mainly comes our Scandinavian neighbors in the following order (Fiskeridirektoratet, 2001a):

- Norway (industrial fish, fresh whole herring, salmon and fresh whole codfish)
- Sweden (industrial fish, fish waste, Fresh herring, fresh codfish etc.)
- The Faeroe Island (industrial fish, fish waste, whole Salmon, whole Shrimps and frozen codfish filets)
- Island (fish meal and oil, prepared herring and whole shrimps)
- Greenland (Whole shrimps, preserved or conserved shrimps and frozen whole flatfish)

For fish products that are based on imported, we may therefore add an extra transport load of 500-1.000 km to the distances in table 1[36].

3b) Products that are re-exported

It is also important to notice that a certain percentages of the exported products are further processed at the destination and subsequently re-exported. This is not included in the table 1. However, it is very difficult to estimate the extra transport load that this may cause. It will depend on each case, and it much be analyzed individually in each case. Among the types of fish products that are exported for further processing are semi-manufactured herring, where the packaging may take place in Germany.

Other modes of transportation (cross continental markets)

Concerning the cross continental markets the most important are Asia especially Japan. There are three of the products in table 1 that are exported to distant markets in significant quantities. That is frozen whole flatfish to Japan and Taiwan, whole shrimp to Japan and Russia and finally frozen whole mackerel to Japan – see table 1.

The sailing distance to from Copenhagen to Tokyo is app. 13.244 km, and the trip takes roughly 25 days with a speed of 23 knots. The distance to Kaoshaing in Taiwan is 11.894 km and it also takes roughly one 25 days with 23 knots (World-Ports distances, 2003). As an average distance to the

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[36] For products that are imported from Greenland, Island and the Fareo Island, the distance may be longer, but on the other hand it will be by ship, which is more fuel-efficient.

Asian market it roughly 12.500 km and 25 days. Data from the Swiss ETH database in SimaPro 5.1[37] as well as the Green network suggest an energy consumption of 0,14 MJ per ton km[38] for container ship, sailing with 23 knots and with a total capacity of 47.000 ton (SimaPro5, 2003; Green Network, 2000). The energy consumption for one kg fish is therefore, roughly:

0,14MJ per tonkm*12.500 km*0,001ton = 1,75 MJ per kg

Apart from this it should be considered that the products will be transported by truck to and from the harbor. If this is a total distance of 1.000 km the total energy consumption would be roughly 2,5 MJ per kg fish product. Apart from that the products must stay cooled in the whole period. Hence the consumption may be even bigger.

Other modes of transport (all markets)

The previous estimations of the transport load mainly deals with road transport. Alternatives could be train, ship and air transport. Just to give an overall picture of the transport in EU it can be established that the amount of freight transport by road is around 44 %, while 41% is by ship, measured in tonkm. Ships travel an average distance of 1.430 km, while trucks average distance is 110 km. Only small amounts of freight is transport by air, which constitutes app. 0,7% of the total freight transport in EU, measured in tonkm. However, this is for average freight and the situation may be different for fish products.

Train

In a Norwegian study of fish transport between Norway and Italy, it is argued that transport by train may reduce the fuel consumption between 9-79%. The study argues that increased time use is not an important barrier (5% difference) and that train in some cases may be faster compared to road transport by lorry (Andersen, 2002b).

[37] Average container ship (47000 ton), sailing at relatively high speed (23 kn= 43 km/hr). This is applicable for products but not for bulk transport. loading 65%, ETH data (SimaPro 5.1, 2003)

[38] The Danish PC tool TEMA suggest that a containership has a fuel consumption of 0,2-0,3 MJ per tonkm. However, this is for a relatively small ship, with a total capacity of 11.000 ton, which is not representative for a a long distant transport to Asia.

According to the EDIP database the fuel consumption for transport by train is 0,7 MJ per tonkm (Drivsholm et al. 2002). According to the most resent version of the TEMA database the fuel consumption 0,51 MJ per ton km for typical Danish freight trains (TEMA, 2000). Other Danish references mention 0,43 MJ per tonkm (Green Network, 2000). Probably the most reasonable estimate is the one from the TEMA report suggesting 0,51 MJ per ton km. If it is assumed that the transport distances are similar, this implies a reduction of the energy consumption of 38% for frozen products compared to transport by lorry, which is in the middle of the interval suggested by Andersen (2002b)

However, a German study where freight transport by road and train are compared it is concluded that train, is not always better than road transport and that the improvement potential generally is small. First of all, the freight cannot be transported from door-to-door by train - with very few exceptions. Thus, lorries have to fill the missing gaps, anyway. Secondly, most freight involves only one lorry load, and a lot of freight eventually have to be transported even further than necessary compared to the more direct road transport. (IRU & BGL, 2002)

It is obvious that the advantage of road transport is the flexibility, and train is probably not well suited for all kinds of fish products. However, for products such as conserved, salted and dried fish products train may be an environmentally sound alternative for freight over long distances, where the extra transport by road in both ends, is limited.

Ship

Transport by ship is mainly used for trans-continental export, and here it is suggested that the energy consumption is 0,14 MJ per ton km, as earlier explained. If ships were used to transport fish within Europe – there will probably be used some smaller ships. The Danish TEMA database suggest 0,2-0,3 MJ per ton km for carriers with a capacity of 11.000 tons, a utilization rate of 65% and a speed of 17,5 knots (TEMA, 2000). If we assumed that the distance were the same as for road transport and that there was not additional need for road transport the energy reduction would be reduced with 70%. However, this is not the case. In the Norwegian study of fish transport it is concluded that ship transport is in fact more energy consumption than road transport when everything is included (Andersen, 2002b)

Air-transport

As mentioned it is only small amounts of freight is transported by air in EU. However, air-transport of high quality fresh fish over long distances is a know phenomenon. An LCA study of air transport in the US using Input/output modeling, show that fish products are among the 10 most air-transport demanding commodities in the American economy (Kaenzig, 2003).

Transport by air is very energy demanding – especially for shorter trips, as the start consumes considerable amounts of energy. Drivsholm et al. (2002). Table 2 include data for energy consumption for different transport distances based on figures from Scandinavian Airlines

Table 2. *Fuel consumption for different transport distances by means of air-transport – based on environmental account from Scandinavian Airlines (SAS, 2003)*

	National (300 km)	**Europe (1.500 km)**	**Tran-continental (10.000 km)**
Kg fuel per RTK[39]	0,59	0,63	0,27
MJ per RTK	25,5	27,2	11,7
MJ per kg per total distance	7,7	40,1	117

Based on these figures it can be established that the energy consumption is considerable larger compared to all other modes of transport truck, ship and train.

The domestic market

As mentioned in chapter 2 the domestic market is not important in size, but it may still be important for product development etc. It has not been possible to establish a picture of the sale of different kind of fish products on the home market, but among the popular products produced in Denmark are canned mackerel, pickled herring, cod and flatfish filets, breaded and filled filets as well as shrimps.

The transport distances are roughly 100-500 km. As the present dissertation mainly deals with products caught by Danish fishermen and processed by

[39] RTK means Revenue Tons Kilometers. This means that it is only passengers or freight that pays over a certain limit that are included in the calculations. This means that the figures will be slightly overestimated (SAS, 2003)

Danish fish industries, this can be used as a good estimate. Otherwise we may need to add a transport load of at least 500-1000 km, as previously mentioned.

A 7.2 Chemical exchanges

Cooling agents is another issues that should be considered. During transport the products are cooled by ice, but there is also air-conditioning in the freight containers. The energy consumption for this process is included in the energy consumption for transport but the cooling agents are not.

It must be considered that some products are transported to destinations such as Japan by ship. As described in the next section the journey to Japan may take up till one month – roughly. According to Pedersen (2001) cooling containers are used in a rough environment and the loss of cooling agents can therefore be significant. The cooling agent is typically HFC 134 a, which have a global warming potential of 1.300 CO2 equivalents after 100 years and a ozone depletion potential close to zero. The publication does not give any estimates of the loss in cooling containers, but it is assumed that the consumption is similar to that of retailers, where there also is a great loss of cooling agent due to long pipe distances – see chapter 6. For transport by lorry – the transport time is typically 1-3 days. Thus, the consumption and emission of cooling agents will be insignificant.

A 7.3 Development tendency

The distribution in the value of the international trade with fish and fish products has increased with a factor 16 from 1970 to the end of the 1990s. Agricultural products have only increased with a factor 6 in the same period (Nordisk Ministerråd 1998a, p. 65).

The amount of freight transport by road in EU have increased with 4,2% annually from 1970-1997 measured in ton km, and 3,5% annually for ship – covering all products. In the same period transport by rail have decreased with 0,3% annually. Hence, the road transport have increased with a factor 3,1 while ship transport have increased with a factor 2,5. Finally transport by rail has decreased slightly.

It is extremely difficult to predict the future development in transport load of fish products. A report by Foreningen af Danske Eksportvognmænd (1995) suggest that the demand for road transport will generally increase over the next 10-15 years, even though environmental considerations, will pull in the other direction. The projection is based on two scenarios that include a great number of variables. Not a single variable in any of the studies points towards a reduced need for transport, but it is suggested that the transport will become more efficient by means of technology improvements, better engines, improved logistics etc. (Foreningen af Danske Eksportvognmænd, 1995)

The technological aspect also concerns other modes of transport such as train, ship and plain. Engines are continuously being improved and new emission norms are gradually being introduced or tightened (Drivsholm et al. 2002; Miljøstyrelsen, 2003)

Thus, we probably have to opposite tendencies – the technological development towards reduced emissions per tonkm for all modes of transport, and an increasing demand for transport. Hence, it is likely that a future transport scenario for fish products in terms of environmental impacts will remain on the level of magnitude, as we see to day. However, there may be certain emissions such as SO_x and NO_x that will be reduced considerably over the next 10-15 years, due to new emission regulation, especially within lorry transport. (Drivsholm et al. 2002; Miljøstyrelsen, 2003)

App. 8: Exchanges at the Use Stage

This appendix include background information and calculations used for the MECO analysis concerning the use stage - described in chapter 6.

A8.1 Water consumption

According to Wrisberg (2001) the total water consumption related to kitchen activities is 50 liter per person per day. If it is assumed that one kg of fish cover 35-100% of the total energy demand for a person per day[40], this would suggest that the water consumption would be 18-50 liter per kg fish.

This includes food preparation and dishwashing. The water consumption for food preparation and dish washing depends on many variables. Therefore it has been chosen to use data from professional kitchens where it is established that 36 % of the water consumption is related to food preparation and cleaning while 64% is related to the dish washing (Green Network, 2002).

This would suggest that the water consumption is:

- 6,5-18,0 liter per kg fish for food preparation (12 liter in average)
- 11,5-32,0 liter per kg fish for dishwashing (17 liter in average)

This is the same as an average total of roughly 30 liter per kg meat. However this figure cover both dish washing in machine and in hand. The following sections elaborate further on different dishwashing techniques.

Dishwashing in machine

According to Grøn Information (2001a) the water consumption is typically 12-18 liter of water per 12 dishes using washing machine. The filling of the machine may vary between 50% and 100% - but it is assumed that it is 75%

[40] The normal energy intake is around 10 MJ per person per day and the energy content in one kg fish varies from 3,5-10 MJ per kg (Veterinær og Fødevaredirektoratet, 2000; Andersen, 1998).

full in average. Thus, the water consumption will be 16-24 liter per 12 dishes or roughly 2 liter per dish in average.

If the meat content of a typical meal is assumed to be responsible for 1/3 of one dish, and if we need 10 meals to make 1 kg meat - this is nearly 7 liter of water per kg fish served fish[41]. This is considerably less than the 17 liter that was suggested as an average in previous section. One factor important than can explain the difference is that we have not included water for initial rinsing, which may increase the consumption considerably.

Dishwashing in hand

There exist few good studies of dishwashing in hand. However, a recent German study actually appears to be relatively reliable. The study includes is based on studies of 75 consumers in seven different European countries. According to Stamminger[42] (2002), it requires 15-345 liter or roughly 90 liter in average to do the 12 sets of dishes (the typical maximum load for a machine). If again we assumed that the meat is responsible for 1/3 of a dish and that we need 10 meals to consume one kg of fish - the water consumption becomes 25 liter of water per kg served meat. This is more than the 17 liter suggested by comparing Wrisberg (2001) and Green Network (2002), but it appear that the true figure for the average water consumption indeed is somewhere in-between the data for dishwashing in hand (25 liter) and dishwashing by machine (7 liter). Thus, the 17 liter initially suggested as the average appear to be a relative good estimate in all cases.

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[41] Recipes typically suggest a meat content of a dinner in the region of 1/3 of the portion or approximately 100 gram (www.aom.dk). According to Veterinær og Fødevaredirektoratet (2000) the daily energy intake for an adult is roughly 10 MJ per day. The same reference suggests that 25% of the daily energy intake should be the evening dinner. Thus, the energy intake is roughly 2,5 MJ per person per dinner. A meat content of 100 gram per person, would be the same as 0,35 MJ for lean fish while it would be around 1 MJ for oily fish (Andersen, 1998). Based on energy content the fish would therefore make up 15-40 % of a typical dinner, if there is used 100 gram fish meat in a 300 gram dinner. Thus, in average the difference on a mass and energy content allocation would not make a significant difference.

[42] It should be notices that Stamminger have been chief of development for Electrolux, and is currently vise president in the European committee of white goods producers (CECED).

A8.2 Energy consumption shopping

The activities before cocking include shopping and cold storage in refrigerator or freezer.

Modal split and distance

In a Swedish study it is conclude that the average consumer uses the car for shopping in 60% of all cases, while the average distance is 7,8 km (round-trip) in Sweden in 1998 (Orremo and Wallin, 1999). A similar study from United Kingdom suggest that the average distance per shopping trip was 5,2 miles or roughly 8,3 km in 1995 (Gould and Golob, 2002). A third study, also from UK, suggest that the modal split for shopping measured in distance in UK in 1998 was walk/bicycle (5%), car and other private (82%) and public transport (13%). The study also presents the modal split measured in number of shopping trips. In this case car and other private only make up 53% of the trips.(Anable, 2002). This shows that car is used in roughly half of the cases but the shopping trips are typically longer.

For the present study, the model split measured in distance is more relevant, and indicates that shopping by car is the most commonly used mode of transport in Europe. Based on the studies it is assumed that the average shopping distance is 8 km, and that the shopping is performed by car.

Allocation

It must be assumed that there is bought several products per trip and the exchanges should obviously be allocated between these goods. The total purchase will depend on factors such as product volume, weight and value of the groceries. However, there have not been data available for average weight and volume of groceries for a typical shopping trip. Thus, economical allocation has been used as the best alternative

Economical allocation.
According to Orremo and Wallin (1999) Swedish consumers spend in average 208 Skr per shopping trip in 1998. This does not represent all European countries, but is the best estimate available.

The exchange rate between Skr and Dkr has been around 0,82 in average for the past couple of years (Nordea, 2003). Thus, the average purchase would be similar to roughly 171 Dkr, if the exchange rate reflects the difference in purchasing power for fish products.

The price of one kg of fish products depends on many variables such as the country in which it is purchased and the type of fish products. It is obvious that the price may vary considerably.

According to the Danish national statistics the average household used 837 Dkr on fish products per year in the period 1999-2001. The average number of persons per household was 2,1. Thus, the average spending on fish, was roughly 400 Dkr per person per year (Danmarks Statistik, 2003). According to Fiskebranchen (1998) the average fish intake per adult is 9,1 kg while children consumed 6,0 kg of fish in average in Denmark. If it is assumed that the average fish consumption is 7,5 kg per person per year, the price of fish would be 53 Dkr per kg in average. This figure appear to relatively low and it has therefore been chosen to supplement the figure with prices on varies fish products obtained from three Danish retail stores[43].

[43] The prices are obtained the July the 28th 2003 in the respective retail stores in Århus (Denmark)

Table 1. *Fish prices (Dkr.) and allocation factors based on economical allocation for different species categories*

	Salling super	Føtex	Netto	Average	Allocation
Codfish (cod)					
Filet IQF	112	-	-	112	65%
Filet block frozen	120	-	100	110	64%
Filet fresh	-	155	-	155	91%
Flatfish (plaice)					
Filet IQF	100	100	80	93	54%
Filet breaded	-	85	80	83	49%
Filet fresh	-	160	-	160	94%
Shrimp					
Peeled (IQF)	125-250	90-100	72-133	128	75%
Peeled fresh	188-239	230	-	222	130%
Norway lobster					
Peeled (IQF)	353	-	-	353	206%
Blue mussel					
Peeled (IQF)	100	-	-	100	58%
Peeled fresh	100	100	-	100	58%
Herring					
Pickled (filet)	63-106	67-90	40-75	74	43%
Mackerel					
Filet canned	45	43-45	38-65	47	27% (42%)[44]

As it appears there are great variations, and the table suggests that we should consider each product type individually. As a average estimate 53 Dkr. Per kg which is similar to an allocation of 31% of the exchanges from shopping appear to be in the low end. A more reasonable estimate would probably be something like 80 Dkr per kg, which is an allocation factor of 46%.

Specific energy consumption for cars

According to Green Network (2000) the average energy consumption for car is 2,45 MJ per km[45]. This is similar to roughly 15 km per liter of fuel if it is assumed that the energy content is 36 MJ per liter of petrol.

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[44] This number considers that part of the net content (typically 125 gram) includes tomato paste and that the meat is only around 80 gram of this.

[45] If it is assumed that shopping only involves a purchase of 5 kg this is similar to 490 MJ per ton km and shows that car transport is an extremely energy demanding mode of transport for small amounts of freight. As mentioned in app. 6 the energy consumption for freight transport by lorry in below 1 MJ per ton km or roughly 500 times less than car.

Results

It is assumed that the average distance is 8 km for a roundtrip and that the shopping is performed by car (15km/l), which provides a total energy consumption of 19,2 MJ per shopping trip. The allocation factors vary from product to product when economical allocation is applied. The results for the different products are illustrated below:

Table 2. Energy consumption for shopping allocated to different types of fish products

	Total energy con-sumption - shopping	Allocation factor	Energy consumption [MJ per kg fish]
Codfish (cod)			
Filet IQF	19,2	65%	12,5
Filet block frozen	19,2	64%	12,3
Filet fresh	19,2	91%	17,5
Flatfish (plaice)			
Filet IQF	19,2	54%	10,4
Filet breaded	19,2	49%	9,4
Filet fresh	19,2	94%	18,0
Shrimp	19,2		
Peeled (IQF)	19,2	75%	14,4
Peeled fresh	19,2	130%	25,0
Norway lobster			
Peeled (IQF)	19,2	206%	39,6
Blue mussel			
Peeled (IQF)	19,2	58%	11,1
Peeled fresh	19,2	58%	11,1
Herring			
Pickled (filet)	19,2	43%	8,3
Mackerel	19,2		
Filet canned	19,2	27% (42%)[46]	8,1

As it appears, two of the allocation factors are larger than 100%. It could be argued that this is not possible. Still, it is considered plausible here because we are considering one kg fish – more than the typical consumer purchase, I would assume.

[46] This number considers that part of the net content (typically 125 gram) include tomato paste and that the meat is only around 80 gram of this.

If I had used the average price of 53 Dkr per kg fish the energy consumption for transport would have been 6 MJ per kg in average, which is somewhat lower than predicted above. If I had used the alternative allocation factor of 46% corresponding to an average prize of 80 Dkr per kg (average of prizes on the product types above) the energy consumption would have been 8,8 MJ per kg fish product. As an average I would assume that the energy consumption is around 7,5 MJ per kg fish/shellfish.

It should be stressed that UK studies suggest that car is only responsible for around 80% of the traveling distance for shopping. Hence, the figure must be considered a worst case.

There are also studies, which suggest that the consumer tend to do other errands, on long trips. In some cases it is even suggested that the consumer tend to make it to a kind of excursion, when the family shops in malls outside the city, and that the distinction between shopping and leisure activities are becoming gradually more blurry (Anable, 2002). This would suggest that the allocation factor should be reduced and stresses that the figure may be overestimated.

A8.3 Energy for cold storing

Another pre-cooking factor is cold storing. The energy consumption depends on the storing time, but also other variables such as the type of freezer (chest freezer versus upright freezer), the type of refrigerator as well as the product volume, utilization etc.

On a more detailed level there is also variables such as the temperature of the products before they are stored, their weight and specific heat capacity, heat loss through door opening, number of door openings, the air temperature in the room, ventilation, temperature adjustment etc. The freezer or refrigerator also contributes to heat warming, which could be included in the calculations. However, for a rough estimate of typical fish products it has not been deemed necessary to take all these variables into account.

As for cold storing in other stages I have focused on four variables, namely the product volume, utilization, storing time and the specific electricity consumption.

Product volume.

As for cold storage during wholesale and retail it is chosen to use volume as a allocation parameter. Over time it must be assumed that it is the volume of groceries that mainly influence, if we tend to buy a larger or smaller freezer or refrigerator, next time[47]. Hence, the volume of the groceries influences the marginal volume and is therefore relevant to use for allocation[48].

According to Weidema et al. (1995) 50% can be used as the utilization factor for cold storage at the consumer stage. A similar utilization factor is used in the Swedish LCA study of frozen cod (Ziegler, 2002).

This means that the effective product volume per kg fish is 10 liter for frozen filet (IQF), 2,5 liter for frozen block filets and 8 liter for fresh fish and perishables.

Storing time

Storing time for frozen products

The storing time is very individual. The freezers are typically 165 liter for upright freezers, and 300 liter for chest freezers (Danske Elværkers Forening, 1998).

If one kg groceries takes up 2,5-10 liter of space in average (considering a utilization of 50%) – this would mean that there is roughly 20-120 kg groceries in an average freezer. If it were assumed that the consumer maximum uses 1 kg of groceries from the freezer each day, and that the freezer is continuously refilled – the average storing time would be at least 20-120 days in average. This is obviously an estimate with based on several uncertain as-

[47] It can always be discussed whether it is reasonable to allocate the energy on a volume basis for the storing. It can be argued that the consumer has a freezer or/and a refrigerator anyway, and that it is just a question of using it as much as possible. The more it is used the smaller the energy consumption becomes per product seem to be the logic. Nevertheless this logic would lead to the assumption that the energy consumption for storing of groceries is zero. It would also imply that we buy a freezer or refrigerator – not because we need the function of it but because we just perceive it as a part of the kitchen. Although this logic may appear to have some truth built into it – it is hopefully only true to a limited extent.

[48] This is also the conclusion in Weidema et al. (1995)

sumptions. Based on the figures above as well as common sense there is used three scenarios, two weeks, one month and two month for frozen products.

Storing time for fresh fish and perishables
For fresh fish it is assumed that the fish is eaten within one to three days, which reflects the short durability of these products (Andersen, 1998).

For perishables the durability is similar to that of frozen fish (Fiskebranchen, 1998). Thus, I have chosen to use the same scenarios for storage time as frozen fish. This can also be used as a rough estimate for smoked, and salted salted products, although it is probably slightly overestimated

Specific electricity consumption

Freezers
According to Danske Elværkers Forening (1998) the energy consumption for average modern 165 liter upright freezers is 0,024 MJ per liter per day, while an average modern 300 liter chest freezer have an energy consumption of 0,012 MJ per liter per day. Thus a chest freezer is approximately double as effective as an upright freezer. The average energy consumption is estimated to 0,018 MJ per liter per day[49].

Refrigerators
According to Danske Elværkers Forening (1998) the energy consumption for average modern 200 liter refrigerator is 0,012 MJ per liter per day or 0,08 MJ per liter per week. The average is 0,010 MJ per liter pr day

Results

The results for the total energy requirement for different types of fish products are illustrated in table 2, below.

[49] In a Swedish LCA study of codfish there is used a modern freezer with a energy consumption of 0,015 MJ per liter per day (Ziegler, 2002).

Table 2: *Energy requirement for cold storing in the consumer stage*

Time	Three scenario for storing time [days]			Volume [liter]	Specific energy consump. [MJ/l/day]	Corresponding scenarios for energy requirement [MJ/kg]		
	Short	**Med.**	**Long**	**Average**	**Average**	**Low**	**Av.**	**High**
IQF fish	14	30	60	10	0,02	2,52	5,4	10,8
Block fish	14	30	60	2,5	0,02	0,63	1,35	2,7
Fresh fish	1	2	3	8	0,01	0,08	0,16	0,24
Perishables	14	30	60	8	0,01	1,12	2,4	4,8

As it appear the energy consumption, especially for freezing, can be considerable. In the average scenario (storing one month) is estimated that the energy consumption is 5,4 MJ per kg frozen IQF product and 1,34 per kg frozen block fish[50].

The energy consumption for fresh fish is relatively insignificant considering the short storing time, but the energy requirement for perishables such as pickled herring, can also be considerable (2,4 MJ per kg) as the storing time is considered similar to frozen products (one month in av. scenario).

Methodological discussion

It is obvious that the estimates presented in table x are very uncertain. This uncertainty is partly related to the estimation of storage time and partly the storing volume. However, it must be assumed that the variables are opposite proportional. A small volume per kg would lead to a larger stored amount – thus a larger average storing time. Hence, the real uncertainty lies in the estimated amount of groceries taken out per day. As described I have chosen a maximum of one kg per day. As an average household includes 2,1 persons this must be assumed to be a high estimate and this points towards even higher storage time.

[50] According to Ziegler the energy consumption for storing of block codfish at the consumer stage is only 0,5 MJ per kg. However, this figure is based on a storing time of two weeks, while my figure is based on a estimated storing of one month. Considering this difference it must be concluded that the two estimates are quite similar.

A8.4 Energy - food preparation

Food preparation of fish also consumes energy, unless we are considering some types of canned products e.g. pickled herring. The primary energy consumption is related to the use of traditional oven, microwave oven or stove.

Energy consumption for mixed recipes

Three fish recipes and the energy total consumption

There have been data available for the energy consumption for three fish recipes. The recipes include:

- Flatfish filets: 150 steamed flatfish filet with carrots (prepared on stove and microwave oven). The total amount of ingredients is roughly 300 gram
- Fish Florentine: 400 gram cod filet with spinach (prepared in oven and microwave oven). The total amount of ingredients is roughly 800 gram
- Green fish paté: 400 gram codfilet with mixed vegetables (prepared in oven and microwave oven). The total amount of ingredients is roughly 800 gram.

As it appear the typical fish recipes contain roughly 50% other ingredients such as vegetables, margarine, onion, eggs etc (Københavns E, 2002).

Table 3. *Total energy consumption for the different recipies (Københavns E, 2002)*

	Steamed flatfish filet [MJ]	Fish Florentine [MJ]	Green fish paté [MJ]
Stove	0,43		
Oven (trad./warm air)		2,88	2,52
Microwave oven	0,22	1,08	0,72

Allocation

There can be used different allocation methods but as the ISO standard recommends system expansion and as this in fact is possible here – system expansion I chosen. I this regard I would argue that the meat (in this case the fish) often decides, which type of recipe there is used and weather even, stove or microwave oven is used. Thus, the meat becomes main responsible for the energy consumption (in some sense the determining product). However, the meat should not be ascribed all the exchanges as we also prepare a similar amount of vegetables. In this regard I have considered the avoided exchanges related to the preparation of these vegetables separately on a stove (probably the typical way to prepare most vegetables separately).

Based on information in the publication Københavns E (2002) it can be established that it requires roughly 0,4 MJ in average to prepare 400 gram of potatoes or 1 MJ per kg on a stove. Carrots, spinach, and mixed vegetables probably require considerably less, but specific data have not been available.

Energy allocated to the fish

Based on the data provided it is not possible to estimate to total energy consumption for the three recipes, applying system expansion.

Table 4. *Total energy consumption for one kg of fish in thee different recipies, where co-product allocation is avoided by system expansion (Københavns E, 2002)*

	Steamed flatfish filet [MJ]	Fish Florentine [MJ]	Green fish paté [MJ]
Stove	1,87		
Oven (trad./warm air)		6,2	5,3
Microwave oven	0,47	1,7	0,8

In a Swedish LCA study of frozen cod it is estimated that the energy consumption is 6,7 MJ per kg if prepared in a traditional electric oven (Ziegler, 2002). This is close to the figures presented above and the difference is mainly because the Swedish study allocates all the energy to the codfish.

Methodological discussion
The figures mentioned so far only consider the direct energy consumption related to cooking in oven etc. However, cooking also involves the use of hot water, ventilation and light.

Concerning ventilation, an electric fan will consume a certain amount of energy, but it will also suck out hot air that eventually is replaced with external air, maybe cold air. If the windows are opened instead, the replacement of hot air with cold air may be even bigger. Still, it should also be considered that the electric equipment generates heat, which substitutes other heating sources. Thus, we both have some factors that would lead to increased energy consumption and some that do the opposite. Although all these factor may lead to slightly higher energy consumption in the usage stage this is disregarded here.

Another factor that may influence the results are whether the fish is frozen or not before preparation. In this regard there can probably be saved a certain amount of energy if the fish is taken out of the freezer an put into the refrigerator in the morning. This will reduce the energy consumption for both refrigerator and heating during food preparation. The exact potential for energy savings has not been assessed.

Energy consumption for different types of ovens

As table 4 points out, the energy consumption is largest for preparation in traditional oven. In this respect there is not any significant difference between traditional and hot air oven – even though the latter is slightly more efficient. However, a gas-oven has significantly higher energy consumption compared to electric oven, but in this case wee need also to consider emissions related to gas versus electricity production.

Mini-oven
If the type of food requires a real oven, it appears that the largest potential for energy savings is related to the size of the oven. A mini-oven can save a lot of energy for small portions – see table 5.

Table 5. *Energy consumption for different types of ovens (Københavns E, 2002)*

	Initial heating 200°C	***Continual heating 200oC (one hour)***
Mini oven (el)	0,36 MJ	1,8 MJ
Electric oven	1,8 MJ	2,5 MJ
Gas oven	2,2 MJ	4,3 MJ

The amount of food prepared does influence the energy consumption very much, and it is therefore important to prepare as much food as possible. Hence, for larger portions the energy consumption may be significantly lower than illustrated in table 4. The opposite is obviously the case for smaller portions.

Microwave – the most efficient

Microwave oven is the most energy efficient methods for food preparation. In a microwave oven the amount of food prepared is directly proportional with time consumption, and therefore also the energy consumption. For small portions the microwave oven is extremely efficient. Yet, microwave oven is probably not always a good alternative to traditional oven s some recipes require heating in traditional oven.

Pan frying

In the case study of flatfish in part two there is gathered detailed data for pan-frying of breaded flatfish filet. This case study shows that the filets gain 17 gram weight under frying, which is mainly do to the margarine, which is soaked up in the breading. The total energy consumption is measured to be 230 Wh, of which 145 Wh was for melting the margarine. The total frying time was 6 min. This is similar to 920 Wh per kg or 3,3 MJ per kg fried breaded flatfish filet. In this study there was used a traditional electric stove (Electrolux, 2002) – the test I available in the excel file on the CD (app. 8 document A)

In this regard, induction stoves are more efficient than ceramic stoves, which are more efficient than traditional electric stoves and gas stoves. Still, the difference is relatively insignificant[51] in many cases. Other factor is more important such as if the pan or pot is covered with a lid, whether the temperature is continuously regulated and whether there is used after heat. (Københavns E, 2002)

[51] According to Danske Elværkers Forening (1998) induction stoves uses 0,50 MJ to boil one liter of water, while the ceramic and traditional stoves uses respectively 0,65 MJ and 0,72 MJ.